ISBN 978-1-927797-02-0
ISSN 1198-273X

PICES SCIENTIFIC REPORT
No. 44, 2013

Report of Working Group 24 on Environmental Interactions of Marine Aquaculture

NORTH PACIFIC MARINE SCIENCE ORGANIZATION

PICES

PICES SCIENTIFIC REPORTS

Published since 1993, the PICES Scientific Report series includes proceedings of PICES workshops, final reports of PICES expert groups, data reports and reports of planning activities. Formal peer reviews of the scientific content of these publications are not generally conducted.

Printed copies of Scientific Reports are available upon request from

PICES Secretariat
P.O. Box 6000
Sidney, British Columbia
Canada. V8L 4B2
E-mail: secretariat@pices.int

On-line versions of PICES Scientific Reports can be found at
www.pices.int/publications/scientific_reports/default.aspx

This document should be cited as follows:

Abo, K., Burgetz, I. and Dumbauld, B. (Eds.) 2013. Report of Working Group 24 on Environmental Interactions of Marine Aquaculture. PICES Sci. Rep. No. 44, 122 pp.

PICES Scientific Report No. 44
2013

Report of Working Group 24 on Environmental Interactions of Marine Aquaculture

Edited by
Katsuyuki Abo, Ingrid Burgetz and Brett Dumbauld

August 2013
Secretariat / Publisher
North Pacific Marine Science Organization (PICES)
P.O. Box 6000, Sidney, BC, V8L 4B2 Canada
E-mail: secretariat@pices.int
Web: www.pices.int

Contents

Acknowledgements

The editors would like to thank the members of Working Group 24 for their contributions to the country reports, and to Mark Higgins (Fisheries and Oceans Canada), S.V. Mikhaylov (TINRO-Center), Norihisa Oseko and Motohiko Sano (Fisheries Research Agency), and Christa Speekmann and Stan Bruntz (U.S. Department of Agriculture) for their contributions to section 3. Laura Hoberecht and Michael Rust are also gratefully acknowledged for constructive comments on the U.S. reports in sections 1 and 2.

Abbreviations and Acronyms

AAVLD	American Association of Veterinary Laboratory Diagnosticians
ACOE	U.S. Army Corps of Engineers
AFS	American Fisheries Society
AGIP	Aquaculture Ground Improvement Program (Japan)
APHIS	Animal and Plant Health Inspection Service, USDA
AVS	acid volatile sulfide
BC	British Columbia (Canada)
BCWD	bacterial coldwater disease
BGD	bacterial gill disease
BKD	bacterial kidney disease
BOD	biological oxygen demand
C	Carbon
CAAPBL	Charlottetown Aquatic Animal Pathogen & Biocontainment Lab (Prince Edward Island)
CAD	Canadian dollars
CAHS	Centre for Aquatic Health Sciences (Campbell River, BC)
CEMA	Coastal Environment Management Area (Korea)
CFIA	Canadian Food Inspection Agency
CFR	Code of Federal Regulations (USA)
CIMTAN	Canadian Integrated Multi-Trophic Aquaculture Network
COD	chemical oxygen demand
DAA	Department of Aquaculture and Agriculture (USA)
DFO	Fisheries and Oceans Canada
DMR	Department of Marine Resources (Maine, USA)
DO	dissolved oxygen
EA	environmental assessment
EBM	ecosystem-based management
ED	Embayment Degree
EHN	epizootic hematopoietic necrosis
EIA	environmental impact assessment
EIBS	erythrocytic inclusion body syndrome
EIS	environmental impact statement
ELISA	enzyme-linked immunosorbant assay
EP	extruded pellets
EPA	U.S. Environmental Protection Agency
EQS	environmental quality standards
ESAP	Law to Ensure Sustainable Aquaculture Production (Japan)
EU	European Union

EUS	epizootic ulcerative syndrome
FAF	Federal Agency for Fisheries (Russia)
FAO	Food and Agriculture Organization of the United Nations
FCA	Fisheries Cooperative Association (Japan)
FDA	Food and Drug Administration (USA)
FHPR	Fish Health Protection Regulations (Canada)
FWI	Freshwater Institute (Winnipeg, Canada)
FWS	Fish and Wildlife Service (USA)
GFC	Gulf Fisheries Centre (Moncton, Canada)
GIS	Geographical Information System
HAA	Health of Animals Act (Canada)
HAB	harmful algal bloom
HAR	Health of Animals Regulations (Canada)
HDPE	high-density polyethylene
I&T	introductions and transfers
ICES	International Council for the Exploration of the Sea
IHHN	infectious hypodermal and hematopoietic necrosis
IHN/IHNV	infectious hematopoietic necrosis/infectious hematopoietic necrosis virus
IL	ignition loss
IMTA	integrated multi-trophic aquaculture
IPN/IPNV	infectious pancreatic necrosis/infectious pancreatic necrosis virus
ISA/ISAV	infectious salmon anemia/infectious salmon anemia virus
ISKNV	infectious spleen and kidney necrosis virus
ISL	Index of Suitable Location
ISO/IEC 17025	International Organization for Standardization for quality systems in testing and calibration laboratories; used as the basis for accreditation of laboratories
JFRCA	Japan Fisheries Resource Conservation Association
JSA	joint subcommittee on aquaculture (USA)
KHV/KHVD	koi herpesvirus/koi herpesvirus disease
MAFF	Ministry of Agriculture, Forestry and Fisheries (Japan)
MLLW	mean lower low water
MOE	Ministry of the Environment (Korea)
MOMAF	Ministry of Maritime Affairs and Fisheries (Korea)
MOU	Memorandum of Understanding
MP	moist pellets
MSX	*Haplosporidium nelsoni*, protozoan pathogen
MT	metric tons
N	Nitrogen
NAAHLS	National Aquatic Animal Health Laboratory System (Canada)
NAAHP	National Aquatic Animal Health Plan (USA)
NAAHP	National Aquatic Animal Health Program (Canada)
NAAPTN	National Aquatic Animal Pathogen Testing Network (USA)
NAHRS	National Animal Health Reporting System (USA)

NEPA	National Environmental Policy Act (USA)
NFRDI	National Fisheries Research and Development Institute (Korea)
NOAA	National Oceanic and Atmospheric Administration (USA)
NRIA	National Research Institute of Aquaculture (Japan)
NVSL	National Veterinary Services Laboratories (USDA)
OIE	Office International des Épizooties (renamed World Organisation for Animal Health in 2003)
OMV	*Oncorhynchus masou* virus
OPC	opportunistic polychaetes
ORP	oxidation-reduction potential
PBS	Pacific Biological Station (Nanaimo, Canada)
PCR	polymerase chain reaction
PFRI	prefectural fisheries research institute (Japan)
PICES	North Pacific Marine Science Organization
POPs	persistent organic pollutants
PVC	polyvinyl chloride
qRT-PCR	quantitative reverse-transcription PCR
RBIVD	rock bream iridoviral disease
RSIV/RSIVD	red sea bream iridovirus/red sea bream iridovirus disease
RT-PCR	reverse transcription polymerase chain reaction
SVCV	spring viraemia of carp virus
TN	total nitrogen
TOC	total organic carbon
TPLMS	Total Pollutant Land Management System (Korea)
TS	Taura syndrome
TVS	total volatile solids
USAHA	U.S. Animal Health Association
USD	U.S. dollars
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
VHS/VHSV	viral hemorrhagic septicaemia/viral hemorrhagic septicaemia virus
VNN/VNNV	viral nervous necrosis/viral nervous necrosis virus
VS	Veterinary Services (APHIS/USDA)
WAHID	World Animal Health Information Database
WSD/WSSV	white spot disease/white spot syndrome virus
WTO/SPS	World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures
YHD	yellowhead disease
YTAV	yellowhead ascites virus

Executive Summary

PICES Working Group on *Environmental Interactions of Marine Aquaculture* (WG 24) was established in October 2008, under the direction the Marine Environmental Quality Committee (MEQ) and Fishery Science Committee (FIS), with the following terms of reference:

- Evaluate approaches currently being used in the different PICES countries to assess and model the interactions of aquaculture operations with surrounding environments.
- Review and assess current risk assessment methods used to assess environmental interactions of aquaculture and determine what, if anything should be changed for application in PICES countries to reflect ecosystem-specific aspects. Following the review and assessment, identify appropriate case studies to compare results among countries in the PICES region.
- Assess methods to detect, identify, evaluate and report on infectious disease events and potential interactions between wild and farmed marine animals. If appropriate, develop a recommended standardized approach for detection/evaluation/reporting from wild and cultured populations. The focus of this activity will be on OIE-notifiable diseases and other infectious diseases of regional/economic importance.

This report is a summary of the activities that WG 24 undertook from 2009 to 2012. The Working Group, with the guidance of FIS and MEQ, refined the activities under the terms of reference so that each PICES member country with active Working Group members could contribute to the report. This refinement was required due to the different types of expertise needed to meet the three very different activities outlined in the terms of reference. Additionally, due to external factors, there was a concomitant challenge in attracting current and new members with expertise in marine aquaculture as well as the resources to dedicate to active participation in the Working Group.

Through topic sessions, workshops and targeted Working Group activities, different aspects of sustainable marine aquaculture research relevant to WG 24's terms of reference were highlighted. Research activities in all PICES member countries focus on identifying aquaculture–environment interactions, whether to model the impacts or to minimize them through optimizing culture approaches, as well as on research related to disease identification and management.

While there are significant differences in species cultured, culture production method and extent, and the regulatory and management structure in place in the different PICES member countries, the Working Group identified some common issues related to environmental interactions of marine aquaculture. These are as follows:

- Marine finfish culture has a more significant influence on the environment than shellfish or algal culture, primarily due to the addition of feed, which can influence the physical, chemical and biological composition and structure of the seafloor below the culture operations;
- The extent of environmental interactions depends greatly on local physical conditions;
- Near-field, or localized, effects are more substantial than far-field (*i.e.*, hundreds of meters or further) effects;
- Far-field effects are not well characterized or researched;
- Rates of ecosystem recovery depend on local physical conditions, but are generally rapid in environments with high water flow;

- Most PICES member countries are at least examining, if not applying, integrated multi-trophic aquaculture to mitigate and improve interactions;
- Pathogen detection and diagnoses are informed by OIE (World Organisation for Animal Health) standards;
- Development and validation of diagnostic methods and dissemination of those methods are ongoing in most PICES member countries; and
- It is recognized that pathogens can transfer between wild and cultured fish.

Although the original terms of reference requested the Working Group to review and evaluate risk assessment approaches for aquaculture, it was determined that while scientific risk assessment of aquaculture activities are being undertaken in PICES member countries, the organizations that are active within PICES are not always the organizations responsible for undertaking these assessments. Therefore, the second term of reference was modified to focus less on risk assessment *per se*, but instead on providing an overview of the legislative framework for evaluating environmental interactions of aquaculture which integrate, either explicitly or implicitly, aspects of risk assessment. An overview of aquaculture regulatory research was also undertaken in order to provide information on funding sources and institutions that have expertise in aquaculture–environmental interactions research.

Based on the experience of WG 24 and the direction of PICES under its FUTURE science plan, some marine aquaculture issues and analysis can be more holistically addressed through expert groups that include consideration of anthropogenic stressor effects on the marine environment. Additionally, any future marine aquaculture-related PICES expert group should be more narrowly focused to not only allow for more directed work, but also to increase the likelihood of experts from all PICES member countries being able to participate and contribute. As well, it is clear that active participation from all PICES member countries is key to realizing a complete analysis of sustainable marine aquaculture issues.

This report is composed of three sections: Assessing environmental interactions of marine aquaculture, marine aquaculture legislative frameworks and environmental interactions research, and pathogens of aquatic animals organized as country reports followed by a summary and recommendations, and appendices which include WG 24 terms of reference (Appendix 1), WG 24 membership (Appendix 2), WG 24 annual reports and topic session/workshop summaries (Appendix 3), and a PICES Press news article (Appendix 4).

1 Assessing Environmental Interactions of Marine Aquaculture: A Review of Long- and Short-Term, Near- and Far-Field Effects of Marine Aquaculture on Benthic Communities, Including Chemical and Physical Changes, and Rates of Ecosystem Recovery in PICES Member Countries

1.1 Overview

This report outlines and summarizes research that has been conducted to date on the environmental interactions of marine aquaculture in PICES member countries, with a focus on interactions with the benthic environment and communities, and spatial (near and far field) and temporal (short and long term) scales, and concluding with recommendations for future work. While the species of fish and shellfish being cultured and methods being used to culture them differ between countries, there are many similarities in the types and extent of benthic environmental interactions of marine aquaculture. In most cases marine fish culture has more significant influence on the environment than shellfish or algae culture, primarily because most fish culture requires feed and that adds more waste to the system which can influence the physical, chemical and biological composition and structure of the seafloor below culture operations. Other similarities are that (1) the extent of environmental interactions depends greatly on local physical conditions, (2) near-field effects are more substantial than far-field effects, but the latter are less researched, (3) rates of ecosystem recovery depend on local physical conditions, but are generally rapid in environments with high water flow, and (4) most PICES member countries are at least examining, and some are applying, integrated multi-trophic aquaculture to mitigate and improve interactions. These reviews complement previous international efforts (Costa-Pierce 2008; GESAMP 2008; Soto *et al.*, 2008; Phillips *et al.*, 2009). Given the focus of PICES on marine science and fisheries, the expanding and important role of aquaculture relative to fisheries in a number of PICES member countries, the history of marine aquaculture and resulting differences in social culture and legislative frameworks amongst PICES member countries (see Section 2), and each country's approach to ensuring the health of its domestic farmed aquatic animals (Section 3), this report will hopefully serve as a good reference and lead to further discussion and application to implementing sustainable aquaculture development at the ecosystem scale (Costa-Pierce, 2010) in PICES member countries.

References

Costa-Pierce, B. 2008. An ecosystem approach to marine aquaculture: a global review, pp. 81–115 *in* Building an Ecosystem Based Approach to Aquaculture, Book 14 *edited by* D. Soto, J. Aguilar-Manjarrez and N. Hishamunda, FAO, Rome, Italy, 221 pp.

Costa-Pierce, B.A. 2010. Sustainable ecological aquaculture systems: The need for a new social contract for aquaculture development. *Mar. Technol. Soc. J.* **44**: 88–112.

GESAMP (IMO/FAO/UNESCO-ICO/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Environmental Protection). 2008. Assessment and Communication of Environmental Risks in Coastal Aquaculture. Reports and Studies 76, Rome, FAO, 198 pp.

Phillips, M.J., Enyuan, F., Gavine, F., Hooi, T.K., Kutty, M.N., Lopez, N.A., Munkung, N.A., Ngan, T.T., White, P.G., Yamamoto, K. and Yokoyama, H. 2009. Review of environmental impact assessment and monitoring in aquaculture in Asia-Pacific *in* Environmental Impact Assessment and Monitoring in Aquaculture. FAO, Rome, Italy.

Soto, D., Aguilar-Manjarrez, J., Brugere, C., Angel, D., Bailey, C., Black, K., Edwards, P., Costa-Pierce, B., Chopin, T., Deudero, S., Freeman, S., Hambrey, J., Hishamunda, N., Knowler, D., Silvert, W., Marba, N., Norambuena, R., Simard, F., Tett, P., Troell, M. and Wainberg. A. 2008. Applying an ecosystem-based approach to aquaculture: Principles, scales and some management measures, pp. 15–35 *in* Building an Ecosystem Based Approach to Aquaculture, Book 14 *edited by* D. Soto, J. Aguilar-Manjarrez and N. Hishamunda, FAO, Rome, Italy, 221 pp.

1.2 Canada

1.2.1 Overview

In 2009, the production of Canadian farmed seafood was 155,000 tonnes, valued at $800 million CAD (*ca*. $700 million USD in 2009). Of this, finfish aquaculture produced 118,000 tonnes or 76% of total aquaculture production, of which 93% was salmon (valued at $653 million CAD (*ca*. $572 million USD in 2009)). Shellfish production was 34,000 tonnes (valued at $64 million CAD (*ca*. $56 million USD in 2009)), with over two thirds, or 68%, of the shellfish production, and half the market value, coming from mussel aquaculture. Aquaculture takes place in all ten Canadian provinces and the Yukon Territory. Production of Atlantic salmon, Chinook salmon, trout, Arctic char, blue mussels, oysters, and clams is well established. Several other species including halibut, sturgeon, tilapia, sablefish and scallops are at various stages of development (DFO, 2009).

The interactions between marine aquaculture and the environment are actively being studied in Canada by federal government, academic and industry researchers. In 2009, a review of the scientific knowledge related to the potential effects of marine aquaculture on the environment was undertaken. This review included an examination of the potential near- and far-field benthic effects on the environment from finfish and shellfish farms. The analysis below is largely taken from the review papers by Page *et al*. (in press), focusing on finfish aquaculture, and Chamberlain and Page (in press), focusing on shellfish aquaculture, (available at www.dfo-mpo.gc.ca/csas).

1.2.2 Fish Culture

Finfish farming in Canada is dominated by Atlantic salmon aquaculture. Based on both empirical and modelling studies, there is strong evidence supporting a linkage between the release of waste feed and fish feces and changes in the physical, chemical and biological composition and structure of the soft-bottom habitat in close proximity to the finfish farm. However, the extent of changes is known to be site-dependent, as the processes which control the scale of effects from waste feed and feces are dependent on local environmental conditions such as temperature, season, hydrography, flushing, bottom type, and bathymetry as well as the characteristics of the ecosystem.

Near-field effects

The extent of the potential effects on the environment from waste feed and feces will depend on the quantity of feed that is used which, in turn, depends on the species being cultivated and the age of the cultivated fish, the time of year and the management practices at the farm. While there are no available empirical data on the proportion of feed that enters the environment as fines (fine particulate matter), it is assumed that this will depend both on the hardness of the feed and the method of feed handling and delivery.

Feed wastage rates are not well quantified, with very few direct measurements available, but typical wastage rates for current farm operations are thought to be 5% or less. Chamberlain and Stucchi (2007) estimated that a feed wastage rate of 5% or greater will constitute more than 50% of the total flux rate of carbon to the bottom, whereas wastage rates of 2–3% are estimated to result in 20–30% of the carbon flux to the bottom. Consistent with a 2–3% rate of feed wastage is the estimation by Ackefors and Enell (1994) that the proportion of feed, in terms of organic carbon, that accumulates on the bottom is about 23% of the material released from the farm. Measured bulk sedimentation rates under and near salmon mariculture cages can vary significantly (>1–181 g C m^{-2} d^{-1}), dependent on environmental conditions, farm size, fish stocking densities and variations associated with measurement methodologies (Wildish *et al*., 2004). However, sedimentation rates in areas without fish farms are typically in the range of 0.1 to 1 g C m^{-2} d^{-1}.

Modelling of waste deposition from finfish farms is being used in Canada in order to predict the footprint of the farm, design sampling protocols for monitoring purposes and to assess the potential impact on the physical, chemical and biological properties of the ecosystem. Based on the sinking rates of feed, fecal and bio-fouling particulate materials, for most Canadian finfish farms the majority of the released materials will sink to the bottom before being decomposed or ingested by wild organisms. The initial bottom exposure associated with waste feed particulates is usually within a few tens of metres of the net pen array, but can be in the range of a few hundred metres in deeper water (Brooks and Mahnken, 2003).

Physical changes

The physical changes associated with the deposition of feces and feed depend, in part, on whether the bottom type is soft or hard. Soft-bottom sites are generally better characterized, and are more prone to smothering. However, waste feed, if found on the bottom in vicinity of farms, tends to be in patches rather than evenly or randomly spread throughout the spatial domain of the net pen or farm lease. The accumulation of wastes is also dependent on currents and tides, which may act to remove wastes from the vicinity of the farms, and will also impact the sinking rates of both feed and feces.

Although research has focused primarily on the potential impacts on soft-bottom substrates, new research is being undertaken in British Columbia (and Newfoundland) that is focusing on hard-bottom substrates (see http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/parr-prra/types-eng.asp for project overviews and information). This research is focusing on both the changes that can be observed or sampled, as well as sampling techniques for monitoring changes. In Newfoundland, finfish farms tend to be located over hard substrates that are homogenous. The accumulation of waste feed and feces may be modulated by currents; however, whether this occurs is site-dependent. In terms of physical changes, a flocculant layer of waste can be found below finfish cages located above the hard ocean substrates. In British Columbia, sites that have been characterized as having hard substrates have been found to be heterogeneous in nature, with some hard substrates mixed in with sponge reefs and soft substrate patches. This complicates the analysis of potential impacts from waste feed and feces, as well as sampling methodology for assessing biological impacts.

Chemical changes

Adding waste food and finfish feces to the environment results in the addition of nutrients. Decomposition and leaching will break down this added organic material, which then results in an increase in dissolved oxygen demand, and releases breakdown products into the sediment and water column. Breakdown rates of waste feed for the Bay of Fundy area, New Brunswick, have been estimated at 5 days to decompose 49% of the carbon within the sediments under finfish farms (Strain and Hargrave, 2005). This estimate is based on measurements of the organic carbon content and oxygen uptake rates of surface sediments with high concentrations of feed pellets and fish feces, and suggests that most of the organic material that is released from finfish farms will decompose on the bottom rather than in the water column, and that sediments should chemically recover quickly (*i.e*., within weeks). This conclusion is consistent with observations (Brooks and Mahken, 2003).

For soft-bottom habitats, the near-field consequences of organic enrichment from aquaculture on the physical/chemical aspects of the habitat include changes in sediment organic content, pore water dissolved oxygen concentration, pH, redox potential, sulphide content, vertical structure of the sediments, and chemical composition of the sediment (sulphides, hydrogen sulphide, methane, carbon dioxide). The extent of these changes is related to the extent of organic enrichment and local environmental conditions.

Biological changes

In general, the effects on the benthic macrofaunal community in response to influxes of organic materials have been well characterized for soft-bottom habitats following a paradigm of species succession along organic enrichment gradients as established by Pearson and Rosenberg (1978). The consequences from organic enrichment (regardless of source) can include changes in biodiversity, species richness and abundance, community structure, and a change in trophic structure.

In soft-bottom habitats, the sediment–water interface is usually aerobic and contains abundant resident macrofaunal and meiofaunal communities. The deposition of feed-related nutrients (*i.e.*, organic-rich materials) results in an increase in aerobic bacteria activity to metabolize the added organic materials. When the rate of deposition exceeds the capacity of aerobic bacteria to metabolize this material, then anaerobic pathways predominate which can lead to the development of hypoxic and/or anoxic environments. In response, the benthic infauna either die off, migrate to the surface layer or the oxygenated water layer above the anoxic zone, or extend and build up their tubes or siphons above the anoxic layer. Death of burrowing macrofauna leads to a rapid decline in the capacity for aeration of the water within the upper sediment profile and a more rapid development of anoxia. In the anoxic interface layer, anaerobic bacteria, principally sulphate reducers and methanogenic bacteria, become prominent. Colonization by opportunistic macrofaunal species that are tolerant of low dissolved oxygen and relatively high levels of hydrogen sulphide, including *Beggiatoa*, and opportunistic polychaete worms (OPC) may occur. In the transition zone between the aerobic and anaerobic zones, low oxygen tolerant species that can exploit the transitional habitat may dominate.

On hard-bottom habitats, the effects of increased organic deposition may be varied. There may be an increase in abundance of suspension and deposit feeding invertebrate species, such as anemones and brittle stars. However, certain deeper-water sessile invertebrate species (*e.g.*, glass sponges, Gorgonian corals, large soft corals, *etc.*) may be particularly sensitive to increased sedimentation, increased organic input or low dissolved oxygen levels and may, therefore, be excluded from the benthic community in the vicinity of marine finfish cage aquaculture (AMR, 2007). As well, there may be a reduction or elimination of small, low profile, sessile species (*i.e.*, hydroids, serpulid worms, tunicates, jingle shells, brachiopods, and encrusting sponges) due to physical smothering from the accumulation of fine sediments (AMR, 2007). Similar to soft-bottom habitats, the sulphur bacteria *Beggiatoa* sp. may be found in hard-bottom habitats in the vicinity of marine finfish cage culture if the decomposition of organic material has led to hypoxic sediments and water at the sediment–water interface. A complex of OPC may be found under similar conditions close to marine finfish farms either in conjunction with, or independent of, *Beggiatoa* sp.

Far-field effects

The intensity of organic loading on the sea floor at distances of hundreds of metres or greater from the net pen array tends to be dominated by fecal release (Chamberlain and Stucchi, 2007), and this loading is considerably smaller than in the near field because the total mass of organics released as feces is generally less than for feed, and is also generally distributed over a larger area. The loading from flocculation is spread over even larger scales (kilometres) at even lower rates (Milligan and Law, 2005).

Resuspension and bedload transport can result in the expansion of the initial exposure domain. However, the extent to which these processes influence the exposure to finfish farm organic wastes is still uncertain and the subject of on-going research.

There is very limited empirical or model-based evidence to characterize the extent of a broader range of exposure to finfish wastes (*e.g.*, Cromey *et al.*, 2002; Brooks and Mahnken, 2003; Chamberlain and Stucchi, 2007) which may be due, in part, to sampling design (*i.e.*, limited sampling beyond a few hundred metres from net pen arrays) and a lack of sensitivity in distinguishing between farm-source wastes and background levels. Targeted research studies are being undertaken within Canada to parameterize the resuspension of wastes from both finfish and shellfish farms over different benthic substrate compositions in order to contribute to addressing some of the uncertainties related to the resuspension and transport of mariculture wastes, and thereby contribute to improving model predictions for finfish (and shellfish) farm footprints (more information regarding this research can be found at http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/parr-prra/types-eng.asp).

Chemical changes

The degree to which the release of dissolved nutrients and organics from cultured finfish operations, either directly or indirectly from the decomposition of wasted fish feed and feces, contributes to the pelagic loading of these substances will depend on the stocking density of fish and the oceanographic conditions of the area. The respiration of the fish and biological oxygen demand associated with the decomposition processes in both the water column and the bottom will also contribute to the removal of dissolved oxygen from the water column. Additionally, the benthic decomposition processes that occur may lead to the injection of hydrogen sulphide, carbon dioxide and methane gasses into the water column (reviewed in Wildish *et al*., 2004).

There is relatively little literature demonstrating eutrophication of the coastal zone associated with finfish culture in Canada. Nutrient loading may be linked to stocking densities, and may correspond to periods of peak production. One of the challenges associated with identifying the potential effects from nutrient additions from finfish aquaculture operations is that there are often many anthropogenic sources of nutrients. Another challenge is that nutrients are rapidly transformed through the primary production process.

The extent that nutrients may be re-suspended and transported depends on both physical and sedimentological processes. Tidal flow, residual circulation, patterns of turbulence, wind and wave energy, and flocculation (aggregation) will determine the large-scale patterns of particle dispersion. The distance and location of accumulation are, therefore, highly site-specific and dependent on bottom topography, currents, erosion and flocculation processes that will affect the residence time of the material both within the water column and on the seafloor (reviewed by Hargrave, 2003).

Biological changes

Should the sedimentation rates at a bay scale be enhanced through flocculation of waste feed or feces from finfish farms, it is possible that fine particulates may coat algae, thus reducing their growth potential, and resulting in bay-scale ecological changes.

The biological consequences of pelagic organic and nutrient loading from finfish aquaculture depend on a number of other factors (*i.e.*, loading rates, water exchange, water column stratification, light penetration, vertical mixing, other anthropogenic activities, *etc*.). Although there is very little research that has examined potential pelagic biological effects of finfish aquaculture activities, the results available are further complicated by a number of influencing factors and the lack of reliable tracers for soluble nutrients from fish farms (Olsen *et al.*, 2008).

The dissolved forms of nitrogen and phosphorus that are excreted by the cultured fish are available to phytoplankton (microalgae), which may result in an increase in phytoplankton biomass downstream from marine finfish aquaculture sites. However, based on monitoring results, dissolved inorganic nitrogen concentrations outside marine finfish aquaculture cages are low at the perimeter of net pens, and essentially undetectable above background levels at 30 m downcurrent from the pens (reviewed in Brooks and Mahnken, 2003). In the Pacific Northwest (Black and Forbes, 1997) and in the Bay of Fundy, phytoplankton production is believed to be light limited rather than nutrient limited (Harrison *et al*., 2005; Sowles, 2005). Therefore, the input of dissolved nutrients from marine finfish aquaculture into the marine environment is unlikely to have a measurable effect on phytoplankton density.

In shallow water littoral and intertidal zones proximal to finfish aquaculture sites, nutrient enrichment can stimulate the extensive development of macroalgal beds, which have a large capacity for nutrient uptake (Hargrave 2003) that may or may not be realized (GESAMP, 2008). This has led to the development of integrated multi-trophic aquaculture approaches which include the cultivation of extractive species such as shellfish and seaweeds.

The species community composition of benthic macrofauna distant from finfish aquaculture sites has not been extensively studied. Long-term monitoring in some areas has generally not found altered benthic community structure or biomass in the far field, but this result is also dependent on the geographic location, depth, and bathymetry of the site.

Overall, there has been a focus on the near-field environmental interactions with finfish aquaculture activities. The potential for far-field and cumulative effects associated with multiple farms has yet to be investigated.

Rates of recovery

Fallowing of sites is used as a management measure in order to allow for chemical recovery of the benthic substrate around finfish net pens. For soft-bottom habitats, once the excess of organic loading ceases, the bottom will recovery naturally. Chemical recovery can occur within weeks to months, whereas biological recovery can take from several months to 2 or more years (Brooks and Mahnken, 2003). The length of time for recovery is dependent on the local environmental conditions.

1.2.3 Shellfish Culture

Shellfish culture in Canada is dominated by suspended mussel culture, which accounted for two thirds of the total shellfish production and half the shellfish market value in 2009. Suspended bottom and near-bottom culture of oysters, intertidal clam culture and scallops are also commercially cultured in Canada. In addition, there are on-going efforts to expand commercial culture to include other shellfish species, including geoducks, quahogs and sea urchins (DFO, 2009).

The majority of research on the environmental interactions of shellfish aquaculture in Canada has focused on the interactions between the environment and suspended mussel culture. However, as part of a 2006 Fisheries and Oceans Canada science advisory process, it was concluded that most effects of bivalve aquaculture are related to the scale *(i.e.*, intensity and extent) of the aquaculture activity, rather than the type of infrastructure (DFO, 2006). Thus, this report will focus primarily on the effects from suspension culture, and will be based largely on the Aquaculture Pathways of Effects review (as above), the 2011 review by McKindsey *et al.*, and on the scientific literature related to suspended mussel culture.

Near-field effects

Suspension culture

Physical changes

The addition of cultured bivalves creates habitat through the addition of both concrete anchor blocks and the mussels and socks that contain them. This addition of structure leads to the addition of habitat and refuges for other invertebrate organisms as well as macroalgae. In addition to the creation of habitat, the placement of the anchor blocks can result in localized destruction of habitat immediately under the blocks. Cultured bivalves that fall off the socks can also create benthic habitat that is conducive to supporting organisms more commonly found associated with hard substrates rather than the soft-substrate habitat that is commonly found where bivalve culture is undertaken in Canada (see review by McKindsey *et al.*, 2011).

The addition of suspended bivalve culture infrastructure can influence hydrodynamic circulation patterns, depending on the spacing of lines, stocking densities, *etc.* If there are bay-wide changes in hydrodynamics (*i.e.*, localized areas of slower currents, *etc.*), they will be specific to the local geography and hydrography.

In addition to the above physical changes, biodeposition of feces and pseudofeces from cultured bivalves may result in an alteration in the nutrient pathways, as well as the accumulation and re-mineralization of the organic matter. As with finfish farms, the extent that this may occur is specific to the stocking density and rate of biodeposit production, initial dispersion of the feces and pseudofeces, redistribution on the seafloor, and the rate of decay (see McKindsey *et al.*, 2011).

Chemical changes

The translocation of organic matter from pelagic to benthic food webs and the excretion of ammonia by cultured shellfish can alter the nutrient dynamics (*e.g.*, recycling rates, retention of nutrients in coastal systems, nutrient ratios) which, in turn, may affect habitat and community structure (Cranford *et al.*, 2006).

Similar to the addition of waste finfish feed and feces, the addition of biodeposits from cultured bivalves may result in an organic enrichment of the benthic community. Depending on the extent of organic enrichment and the local conditions, this may result in chemical changes in the benthic sediment due to microbial metabolism of the added organic materials. In addition to the local physical and bathymetric environment, stocking density, age structure and placement of mussel lines will influence the extent of organic enrichment and potential for shifts in the benthic sediment condition along the oxic to anoxic spectrum.

Biological changes

Dense bivalve populations, as found under culture conditions, can filter large volumes of water, exploiting the diverse nature of suspended particulate matter (the seston), including phytoplankton, ciliates, flagellates, zooplankton and detritus. The rate of filter feeding will influence the extent of local reduction or depletion of the seston by the cultured mussels. The filtration rate by mussels has been found to vary seasonally, and diurnally, compounding the factors required to be considered in assessing the potential influence of mussel culture on the pelagic community.

Generally speaking, cultured bivalves added to an ecosystem can be anticipated to alter the water column biodiversity, particle size and trophic structure through filter feeding. The flushing rate of the bay in which bivalve aquaculture is occurring and the phytoplankton renewal time will determine not only the sustainability of the volume of culture (biomass) that can be supported (production and ecosystem carrying capacity) but also whether there are consequences to the trophic structure. The potential for bivalve aquaculture to influence the trophic structure within the local ecosystem due to removal of specific size ranges (2–8 μm) of phytoplankton through filter feeding has not been assessed.

The addition of suspended bivalve culture to an area has been shown to create habitat and refuges for diverse assemblages of organisms, and to provide a direct food source for other invertebrates. Biofouling organisms associated with suspended bivalve culture include macroalgae, barnacles, hydroids, tunicates, mussel spat and polychaetes. Similarly, the addition of physical structure, either associated with the anchors or mussels that have fallen off, can provide habitat for organisms that are typically found associated with hard substrates rather than with soft substrates. The introduction of biofouling organisms, particularly non-native tunicates and green crab, during shellfish transfers is of concern.

As with finfish farming, when chemical changes associated with the addition of organic nutrients occurs, there is a biological response whereby the benthic infauna productivity may decline if the benthic substrate has high toxic sulphide levels (Cranford *et al*., 2003).

Far-field effects

Far-field effects from suspended bivalve cultures depend on the specific characteristics of the site (*e.g.*, bathymetry and hydrodynamic regime) and the culture operation (*e.g.*, farm size, stocking density, age of operation, age distribution of stock, line placement). Research is being done in Canada to develop models to predict bay-scale and farm-scale effects using site-specific data ranging from flushing rate, phytoplankton renewal time, stocking densities, hydrodynamic and bathymetry information, as well as biodeposition rates. While this research is still being undertaken, initial results suggest that within a bay, there are localized areas with different renewal times, which suggest that model predictions of far-field interactions may require more complexity, particularly if these models are to be used by management.

Far-field benthic effects may occur through different mechanisms, including through the aggregation of macrofauna at culture sites, changes in plankton communities through size selection filter feeding or stimulation of primary productivity due to an increase in nutrient availability and cycling rates, or through the addition of habitat that supports increases in pest species (Cranford *et al.*, 2003; McKindsey *et al.*, 2011).

1.2.4 Marine Algae Culture

Very little marine algae are cultured in Canada, and as such, there is limited research or analysis regarding either near- or far-field effects.

1.2.5 Polyculture/Integrated Multi-Trophic Aquaculture

Integrated Multi-Trophic Aquaculture (IMTA) research has been underway in Canada since 2001. Starting in 2010, a 5-year strategic network, the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN), was funded (http://www.cimtan.ca). This network is designed to facilitate a more strategic approach to Canadian IMTA research focusing in three areas: (1) environmental research (ecological design, ecosystem interactions, bio-mitigative efficiency, and regulatory science), (2) system innovation and engineering, and (3) economic viability and social acceptance.

Some of the research within this network is focusing on assessing candidate organic extractive species based on capture and conversion efficiencies, identifying the temporal and spatial patterns of nutrient and organic particle plumes within IMTA systems and the role of microbes in recycling nutrients, and optimizing stocking densities and infrastructure in order to maximize system efficiencies. Additional information on these and other CIMTAN projects can be found at the CIMTAN website and in the Canadian Aquaculture R&D Review (http://www.aquacultureassociation.ca/aac-news/canadian-aquaculture-rd-review).

1.2.6 Discussion, Analysis, and Recommendations

Aquaculture is one of many anthropogenic activities that is undertaken in coastal zones in Canada. Through siting and licensing requirements, the various regulatory responsibilities in Canada aim to mitigate and manage potential impacts. There continue to be a number of scientific knowledge gaps related to potential environmental interactions with aquaculture, particularly related to being able to assess the cumulative effects of other coastal zone activities, cascading ecological feedbacks from specific effects (*e.g.*, the effect of cultured bivalves removing seston between 2–8 µm on zooplankton and other trophic levels), validated models of interactions, and far-field consequences of environmental interactions with either shellfish or finfish aquaculture (or in the case of IMTA, both). Research in these areas is being undertaken in Canada and internationally. Addressing these knowledge gaps will improve the ability to interpret, assess and manage the environmental interactions of marine aquaculture within an ecosystem context.

1.2.7 References

Ackefors, H. and Enell, M. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. *J. Appl. Ichthyol.* **10**: 225–241.

AMR (Archipelago Marine Research). 2007. Evaluation of hard seabed monitoring techniques: Development of video survey and data classification protocols. Phase 2 Report. Aquaculture E-Fund Project AE 03.04-02.02, July 2007. Archipelago Marine Research, Victoria, British Columbia.

Black, E.A. and Forbes, J.R. 1997. Effects of elevated nutrients from fish farm waste on phytoplankton productivity. Salmon Aquaculture Review, B.C. Assessment Office, pp. D-56–D57.

Brooks, K.M. and Mahken, C.V.W. 2003. Interactions of Atlantic salmon in the Pacific Northwest environment. II. Organic wastes. *Fish. Res.* **62**: 255–293.

Chamberlain, J. and Page, F.H. In press. A review of the Pathways-of-Effects associated with the removal and release of organic material from shellfish aquaculture. Will be available at http://www.dfo-mpo.gc.ca/csas.

Chamberlain, J. and Stucchi, D. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. *Aquaculture* **179**: 127–140.

Cranford, P., Dowd, M., Grant, J., Hargrave, B. and McGladdery, S. 2003. Ecosystem level effects of marine bivalve aquaculture *in* A Scientific Review of the Potential Environmental Effects of Aquaculture in Aquatic Ecosystems. Volume I. Can. Tech. Rep. Fish. Aquat. Sci. 2450, 131 pp. Available at http://www.dfo-mpo.gc.ca/science/enviro/aquaculture/sok-edc/volume1/cranford-eng.htm.

Cranford, P.J., Anderson, R., Archambault, P., Balch, T., Bates, S.S., Bugden, G., Callier, M.D., Carver, C., Comeau, L.A., Hargrave, B., Harrison, W.G., Horne, E., Kepkay, P.E., Li, W.K.W., Mallet, A., Ouellette, M. and Strain, P. 2006. Indicators and thresholds for use in assessing shellfish aquaculture impacts on fish habitat. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/034, 116 pp.

Cromey, C.J., Nickell, T.D. and Black, K.D. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage. *Aquaculture* **214**: 211–239.

DFO (Fisheries and Oceans Canada). 2009. Aquaculture Canada: Facts and Figures. http://www.dfo-mpo.gc.ca/aquaculture/ref/stats/aqua-ff-fc-2009-eng.htm

DFO. 2006. Science Advisory Report (SAR). 2006/005. http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SARAS2006_005_E.pdf

GESAMP (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Environmental Protection) 2008. Assessment and communication of environmental risks in coastal aquaculture. Reports and Studies, GESAMP No. 76, FAO, Rome, 198 pp. http://www.gesamp.org/publications/publicationdisplaypages/rs76. Accessed Nov. 18. 2011.

Hargrave, B.T. 2003. Far-field environmental effects of marine finfish aquaculture. Volume I. Can. Tech. Rep. Fish. Aquat. Sci. 2450, pp. 1–49.

Harrison W.G., Perry, T. and Li, W.K.W. 2005. Effects of suspended mussel culture (*Mytilus* spp.) on sedimentation, benthic respiration and sediment nutrient dynamics in a coastal bay. *Mar. Ecol. Prog. Ser.* **115**: 219–235.

Milligan, T.G. and Law, B.A. 2005. The effect of marine aquaculture on fine sediment dynamics in coastal inlets, pp. 239–251 *in* Environmental Effects of Marine Finfish Aquaculture. The Handbook of Environmental Chemistry, Volume 5, Water Pollution, Part M: Environmental effects of marine finfish aquaculture *edited by* B.T. Hargrave, Springer, Berlin.

Olsen, L.M., Hlomer, M. and Olsen, Y. 2008. Perspectives of nutrient emissions from fish aquaculture in coastal waters: Literature review with evaluated state of knowledge. Fisheries and Aquaculture Research Fund Project No. 542014. Norway. http://www.aquacircle.org/images/pdfdokumenter/udvikling/andre/norden/fhf-nutrients_and_aquaculture.pdf

Page, F.H., Chamberlain, J., Robinson, S., Reid, G. and Chang, B. In press. A review of the Pathways-of-Effects associated with releases of nutrients and organics from finfish netpen aquaculture. Will be available on-line at http://www.dfo-mpo.gc.ca/csas.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Ann. Rev.* **1616**: 229–311.

McKindsey, C.W., Archambault, P., Callier, M.D. and Olivier, F. 2011. Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review. *Can. J. Zool.* **89**: 622–646.

Sowles, J.W. 2005. Assessing nitrogen carrying capacity for Blue Hill Bay, Maine: a management case history, pp. 359–380 *in* Environmental Effects of Marine Finfish Aquaculture. The Handbook of Environmental Chemistry, Volume 5, Water Pollution, Part M: Environmental effects of marine finfish aquaculture *edited by* B.T. Hargrave, Springer, Berlin.

Strain P.M. and Hargrave, B.T. 2005. Salmon aquaculture, nutrient fluxes and ecosystem processes in southeastern New Brunswick, pp. 29–57 *in* Environmental Effects of Marine Finfish Aquaculture. The Handbook of Environmental Chemistry, Volume 5, Water Pollution, Part M: Environmental effects of marine finfish aquaculture *edited by* B.T. Hargrave, Springer, Berlin.

Wildish, D.J., Dowd M., Sutherland T.F. and Levings, C.D. 2004. Near-field organic enrichment from marine finfish aquaculture. Volume III. Can. Tech. Rep. Fish. Aquat. Sci. 2450, pp. 1–67.

1.3 Japan

1.3.1 Overview

In Japan, marine aquaculture produced 1,146,000 metric tons and 418 billion yen (*ca*. 5 billion US$) in 2009, 20% and 26% of Japanese fisheries production in terms of volume and value, respectively. Since mariculture generates large amounts of organic wastes and nutrients in and around aquaculture facilities, it may have large impacts on the benthic environment. Feeding aquaculture (fish farming) discharges a large amount of organic waste into the benthic environment. Although non-fed aquaculture (shellfish culture, algae culture) has less impact, intensive and long-term culture activity causes eutrophication and hypoxia due to feces and associated remnants which may alter the benthic communities in the culture area.

1.3.2 Fish Culture

Yellowtail (*Seriola quinqueradiata*) and red sea bream (*Pagrus major*) are the main species reared in finfish cage culture in Japan. The net cage culture of bluefin tuna (*Thunnus orientalis*) began recently. Fish farming generates large amounts of waste in the form of particulate organic matter, dissolved organic matter and nutrients. In Japan, the negative effects have become conspicuous since the commencement of large-scale fish farming in the mid-1960s and its subsequent rapid development during the 1970s and 1980s. A large amount of organic matter is discharged into the surrounding area resulting in chemical and biological changes of the benthic environment in and around the culture facilities.

Near-field effects

Physical changes

Organic wastes (feces and uneaten feed) derived from fish farming facilities settle on the seabed. In Japan, fish farming is often conducted intensively in enclosed basins and large amounts of sludge accumulate on the seafloor. In such cases, the dredging of sludge under the farming facilities is conducted occasionally to treat the benthic environment even if its sustainability is in doubt.

Chemical changes

A large amount of feed is used to culture fish and a large proportion of resulting organic matter is discharged into the environment in various forms. The flux of organic matter has been investigated mainly from laboratory rearing experiments (Yokoyama, 2010). The proportion of organic matter retrieved as harvested fish has been estimated to be 12% of the total nitrogen in minced raw fish feed (Mie Prefectural Fisheries Experimental Station, 1983) and 26% of total dry matter in the case of moist pellets feed (Watanabe, 1991). The remainder (88 or 74% of the total input of organic matter) results in a load to the surrounding water body. Particulate organic matter that is comprised of fecal matter and waste feed settles on the seabed. Fecal matter accounts for 3% of total dry matter in moist pellets (Uede and Takeuchi, 2007) to 27% of total dry matter in dry pellets (Wakayama Research Center of Agriculture, Forestry and Fisheries, 2002). The proportion of waste feed is variable, accounting for 3% of total dry matter in moist pellets (Wakayama Research Center of Agriculture, Forestry and Fisheries, 2002) to 72% of total dry matter in moist pellets (Watanabe, 1991).

Organic enrichment of the seabed, deoxygenation of the bottom water and occurrence of sulfides are the most significant impacts of fish farming on the benthic environment. In intensive fish farming sites in basins, indices of organic matter loadings (chemical oxygen demand (COD), ignition loss (IL), total organic carbon (TOC), total nitrogen (TN), carbohydrates and amino acid contents in the surface layer of the sediment) become extremely high. Increasing organic enrichment of the sediment has occurred in various fish farming areas in the southwestern part of Japan. Acid volatile sulfide (AVS) in the sediment is commonly used in Japan as an indicator of environmental deterioration in areas with fish farms (Pawar *et al.*, 2001; Yokoyama *et al.*, 2002a,b, 2004; Uede, 2008). Fish farming changes the stable carbon and nitrogen isotope ratios of the sediment due to differences in the ratios between natural sediment and aquaculture-derived organic matter. The stable isotope ratios can be a useful indicator to quantify organic wastes from fish farms in the sediment (Yokoyama *et al.*, 2006).

Biological changes

Fish farming affects the benthic animals beneath the farming facility (Yokoyama, 2010). Kagawa (1983) reported a rapid increase in the ratio of polychaetes in total macrofaunal abundance during the first year at a newly developed yellowtail farm. He also found abnormal dynamics of the benthic communities, including defaunation in summer and recolonization of the azoic areas from autumn to spring, replacement of molluscs by polychaetes, and a decrease of total macrofaunal biomass. Sasaki and Oshino (2004) found an aggregative occurrence of polychaetes beneath coho salmon culture cages.

Fish farming also affects the microbiota on the seafloor of the farming area. Takekawa *et al.* (1989) found the occurrence of the sulphur bacteria *Beggiatoa* spp. on the seabed within a radius of 20 m from coho salmon cages. Rajendran *et al.* (1999) observed increased levels of microbial biomass and increased proportions of the microbial group, including sulfate-reducing bacteria. Sakami *et al.* (2003) found large bacterial production at a fish farm site, suggesting that the loaded organic matter enhanced the bacterial productivity.

Far-field effects

Chemical changes

Dispersion of wastes from fish farms depends on physical factors (current velocity, water depth, resuspension) and aquaculture factors (culture species, amount of feed and type of feed). Many studies reported that the dispersion of organic matter from fish farms is limited to within 50 m from fish cages and that the effects on biotic and abiotic factors have been rarely found to extend more than 250 m from cages. However, Yokoyama *et al.* (2006) reported that the spatial extent of waste dispersal extended to 300 m from fish cages in an intensive farming site of red sea bream. They also reported that enrichment effects on the bottom water and sediment chemistry (low dissolved oxygen content, high level of AVS) extended to a much larger area than the waste dispersal area.

Biological changes

Noticeable effects of fish farming on the benthic fauna are limited to within 50 m from fish cages and there is almost no change of the fauna 120 to 250 m away from the cages (Yokoyama, 2005).

Harmful algal blooms often occur around the fish farming area due to organic matter loading from fish cages. Since the 1970s, the incidence of harmful algal blooms has increased around fish farm areas, especially in the Seto Inland Sea, often resulting in mass mortality of cultured fish (Watanabe, 1991; Imai *et al.*, 2006).

Rates of recovery

Benthic recovery rates vary, depending on water temperature and hydrodynamic conditions within the farming area. There are few studies on the recovery in Japan, but Sasaki *et al.* (2002) reported that COD, IL and sulfide content in the sediment decreased rapidly in 6 months and the levels reached 50% in a year after destocking of cultured coho salmon. They also reported that the benthic animal community structure changed 1.5 years after the destocking. In a fish farm site of yellowtail and red sea bream in Shitaba Bay, AVS in the sediment began to decrease 2 years after removal of cages and reached a low level 5 years after the removal (Wakayama Research Center *et al.*, 2008).

1.3.3 Shellfish Culture

In Japan, oyster (*Crassostrea gigas*) and scallop (*Patinopecten yessoensis*) are the major species of shellfish culture, accounting for 99% of annual production volume of shellfish culture in 2009. Pearl oyster (*Pinctada fucata martensii*) is also an important culture species, constituting 12% of shellfish culture production in 2009.

Shellfish culture has far less impact on the environment than feeding aquaculture such as fish farms. Yokoyama (2002) indicated that pearl oyster farming had less effect on the benthic fauna whereas fish farming had a large impact on the macrofauna. In contrast, shellfish culture systems could act as an efficient biological tool to harvest material from the coastal ecosystem to the land (Songsangjinda *et al.*, 1997). Nevertheless, the cumulative impacts of shellfish culture on the environment may cause eutrophication, hypoxia and changes of benthic communities.

Near-field effects

Suspension culture

Physical changes

Suspended shellfish culture enhances sedimentation due to deposition of feces on the seafloor beneath the farming facility. Fluid resistance of the suspended culture facility reduces the current velocity affecting transport of the materials in the water around the culture area.

Chemical changes

The primary effect of shellfish culture on the marine environment is enhanced sedimentation. Mori (1999) estimated *ca*. 20 metric tons dry weight of feces was produced per year per raft of oyster culture. The fecal production varies depending on culture density (Yamamoto *et al*., 2009). In the case of attached organisms on the farming facility, more fecal materials are accumulated on the benthic environment. Kusuki (1981) reported increases of COD, organic carbon, total nitrogen, total sulfide and phaeo-pigments in the surface sediment in oyster culture sites in Hiroshima Bay. Such increases of organic matter content in the sediments were reported in the oyster culture area of Matsushima Bay, Kesen-numa Bay, and Ago Bay.

Biological changes

Shellfish culture affects the benthic animals beneath the farming facility. In the suspended scallop culture area in Saroma Lagoon, the cumulative impact of the intensive scallop culture affected the polychaete community structure where the species number, density and species composition of the community were changed significantly (Sonoda *et al.*, 2002).

Cultured shellfish excrete high levels of ammonia, promoting increased productivity of organisms attached to the farming facilities. Attached organisms may not only compete for food materials with cultured shellfish but increase biodeposition from the facility to the benthic environment. Production of the fouling organisms attached to hanging lines of scallop culture was estimated to be equal to the scallop production (Kurata *et al.*, 1996). In the pearl oyster culture area, on-site cleaning of fouling organisms leads to an increase of organic matter loading which amounts to 50% of the total organic load of the area (Ueno *et al.*, 2000).

On-bottom culture

Physical, chemical and biological changes

On-bottom culture exploits the sea area two dimensionally and has less production efficiency and less impact on the environment compared to suspension culture which exploits the sea area three dimensionally. Although the impacts are less than for suspension culture, on-bottom culture may play a significant role on surrounding ecosystems by removing organic materials from the water column and enhancing biodeposition to the benthic environment.

Far-field effects

Suspension culture

Chemical changes

Suspended oyster culture affects the cycle of materials in the coastal ecosystem. Songsangjinda *et al.* (1997) quantified uptake of particulate materials from the water column and release of materials to the benthic environment by a raft of suspended oyster culture in Hiroshima Bay. The amount of nitrogen harvested as an oyster product was equivalent to 10% of nitrogen loading in the northern part of Hiroshima Bay. The cumulative organic loading by intensive scallop culture in Saroma Lagoon causes bottom hypoxia, and eutrophication of water (Sonoda *et al.*, 2002). Songsangjinda *et al.* (2000) suggested suspended oyster culture played a significant role in the nitrogen cycle in Hiroshima Bay. Biodeposition by the oyster culture system contributed 36% to the natural sedimentation of the entire bay, playing a vital role in transferring nitrogen to the benthic ecosystem while the oyster culture system showed less significance in nutrient regeneration. Mori (1999) suggested that intensive oyster culture accelerated eutrophication in Matsushima Bay.

On-bottom culture

Chemical and biological changes

Although on-bottom culture has less impact on the environment than suspension culture, it may play a significant role on surrounding ecosystems. On-bottom shellfish culture recovers nutrient loading from the land. Iyooka *et al.* (2008) estimated the reduction of total nitrogen and phosphorus by cultured oysters and oyster reefs in Ariake Bay. The amount of recovery by short-neck clam (*Ruditapes philippinarum*) fisheries is estimated to be about a sixth of the total input of nitrate in Hamana Bay (Furuya, 2004).

Rates of recovery

No scientific information on the rate of recovery of shellfish culture environments in Japan was found.

1.3.4 Marine Algae Culture

Marine algae culture accounts for 38% of the volume of production and 20% of the value produced by aquaculture in Japan in 2009. Nori (*Porphyra yesoensis*) is the major species of cultured marine algae in Japan, accounting for 75% of the annual production volume of marine algae culture. Sea mustard (*Undaria pinnatifida*) and Kombu (*Laminaria* spp.) are also important culture species, accounting for 13% and 9% of the marine algae culture production, respectively.

As marine algae absorb nutrients from seawater and reduce eutrophication, it is regarded that marine algae culture has positive effects on the surrounding environment. However, it may also have a negative impact on the surrounding environment through fouling organisms attached with culture facilities.

Near-field effects

Physical, chemical and biological changes

Fluid resistance of the culture facility reduces current velocity, affecting the circulation and transport pattern of resuspended sediment in Nori aquaculture areas (Yagi *et al.*, 2004).

Cultured Nori absorbs nutrients from seawater. Studies in other countries have investigated nutrient uptake of *Porphyra* in view of the bioremediation potential of eutrophic effluents (Kraemer *et al.*, 2004; Carmona *et al.*, 2006; Pereira *et al.*, 2008). In Japan, studies estimated nutrient uptake rates of *Porphyra yezoensis* (Baba and Miyazaki, 1983; Yamamoto, 1992).

Farming facilities of algae culture support the growth of other attached organisms. Algae culture facilities also provide habitat for spawning and growth of fishes, and increase fisheries productivity of coastal areas.

Far-field effects

Chemical changes

Non-feeding aquaculture recovers loaded nutrients from the land. Since there is no other industrial method of recovery, this function is very important in controlling nutrient cycling between land and coastal waters (Furuya, 2004). Marine algae culture plays an important role in reducing eutrophication in coastal areas. In fish culture areas, recovering nutrients by marine algae culture results in increased fish culture productivity.

Biological changes

Liu *et al.* (2009) reported that Nori aquaculture along the coast caused the occurrence of green tides in Qingdao, China. The thalli of *Enteromorpha prolifera* attached on the culture facilities are able to drift in the water following their removal during the aquaculture activity of Nori. In Japan, however, there is no report suggesting any relationship between Nori culture and green tides.

Marine algae also provide a nursery habitat for juvenile and young fish, thereby enhancing marine resources.

1.3.5 Integrated Multi-Trophic Aquaculture

The use of integrated multi-trophic aquaculture has been proposed for improving mariculture environments. Requirements for available seaweed species in integrated multi-trophic aquaculture include: (1) high efficiency of nutrient removal, (2) high growth during the warm season, (3) high economic value, and (4) easy cultivation (Yokoyama and Ishihi, 2010). Carmona *et al.* (2006) indicated that *Porphyra* appears to be an excellent choice for bioremediation of moderately eutrophic effluents, with the added benefit that tissue may be harvested for sale. In Japan, the effectiveness of integrated aquaculture has been confirmed from experimental fish farms using *Ulva* (Hirata, 2002; Kitadai and Kadowaki, 2004b; Suzuki *et al.*, 2004; Yokoyama and Ishihi, 2010), *Laminaria* (Kitadai and Kadowaki, 2003; Ohyama *et al.*, 2005) and *Undaria* (Kitadai and Kadowaki, 2004a; Kimura *et al.*, 2007) as biofilter species. However, this system has not been adopted on a commercial basis due to the lack of financial reward for the farmer's additional work to implement such measures (Yokoyama, 2010).

1.3.6 Conclusions and Recommendations

Marine aquaculture releases large amounts of organic wastes and nutrients into the environment. Feeding aquaculture has an especially large impact while non-feeding aquaculture, such as shellfish and marine algae culture, has less impact. As marine aquaculture is an essential industry in Japan, we should preserve the aquaculture industry by means of reducing the impacts and environmental footprint. A practical way to ensure sustainable aquaculture production is to evaluate aquaculture environments objectively and conduct aquaculture within the range of assimilative capacity of surrounding environments (Yokoyama, 2010). For this purpose, research and monitoring have been conducted in Japan to estimate the assimilative capacity of aquaculture grounds. Another practical way for sustainable production is the use of integrated multi-trophic aquaculture for recovering organic loadings. Although there have been many experimental studies on integrated multi-trophic aquaculture, this system has not been adopted on a commercial basis at present. We hope multi-trophic aquaculture will be adopted practically by farmers in the near future.

1.3.7 References

Baba, H. and Miyazaki, Y. 1983. Effects of the nutrient concentration and the current velocity on the growth and the nitrogen assimilation of *Porphyra yezoensis*. *Bull. Saga Prefectural Ariake Fisheries Exp. Stn.* **8**: 1–19 (in Japanese with English abstract).

Carmona, R., Kraemer, G.P. and Yarish, C. 2006. Exploring Northeast American and Asian species of *Porphyra* for use in an integrated finfish–algal aquaculture system. *Aquaculture* **252**: 54–65.

Furuya, K. 2004. Environmental carrying capacity in an aquaculture ground of seaweeds and shellfish in Sanriku coast. *Bull. Fish. Res. Agency* **Suppl. 1**: 65–69.

Hirata, H. 2002. Systematic aquaculture: yesterday, today, and tomorrow. *Fish. Sci*. **68**(Suppl 1): 829–834.

Imai, I., Yamaguchi, M. and Hori, T. 2006. Eutrophication and occurrences of harmful algal blooms in the Seto Inland Sea, Japan. *Plankton Benthos Res*. **1**: 71–84.

Iyooka, H., Kusuda, T. and Ogawa, H. 2008, The oyster reef distribution in north Ariake Bay and the environmental effect of oyster cultivation. *Proc. Envir. Engineer Res*. **45**: 501–506.

Kagawa, T. 1983. Fluctuation of benthic fauna communities in the culture ground of young yellowtail. Sci. Rep. Kagawa Prefectural Fisheries Exp. Stn. **20**: 1–8 (in Japanese).

Kitadai, Y. and Kadowaki, S. 2003. The growth process and N, P uptake rates of *Laminaria japonica* cultured in coastal fish farms. *Suisanzoshoku* **51**: 15–23 (in Japanese with English abstract).

Kitadai, Y. and Kadowaki, S. 2004a. The growth and N, P uptake rates of *Ulva pertusa* cultured in coastal fish farms. *Suisanzoshoku* **52**: 65–72 (in Japanese with English abstract).

Kitadai, Y. and Kadowaki, S. 2004b. The growth process and N, P uptake rates of *Undaria pinnatifida* cultured in coastal fish farms. *Suisanzoshoku* **52**: 365–374 (in Japanese with English abstract).

Kimura, H., Noyoya, M. and Fujita, D. 2007. Nutrient uptake by *Undaria undarioides* (Yendo) Okamra and application as an algal partner of fish-alga integrated culture. *Bull. Fish. Res. Agency* **19**: 143–147.

Kramer, G.P., Carmona, R., Chopin, T., Neefus, C., Tang, X. and Yarish, C. 2004. Evaluation of the bioremediatory potential of several species of the red alga *Porphyra* using short-term measurements of nitrogen uptake as a rapid bioassay. *J. Appl. Phycol*. **16**: 489–497.

Kurata, M., Nishida, Y. and Mizushima, T. 1996. Fouling organisms attached on culture scallops, *Patinopecten yessoensis*, in Funka Bay. Sci Rep. Hokkaido Fish. Exp. Stn. **49**: 15–22 (in Japanese with English abstract).

Kusuki, Y. 1981. Fundamental studies on the deterioration of oyster growing grounds. *Bull. Hiroshima Fish. Exp. Stn.* **11**: 1–94 (in Japanese with English abstract).

Liu, D., Keesing, J.K., Xing, Q. and Shi, P. 2009. World's largest macroalgal bloom caused by expansion of seaweed aquaculture in China. *Mar. Pollut. Bull.* **5**: 888–895.

Mie Prefectural Fisheries Experimental Station 1983. Examination of moist pellets to prevent self-induced pollution. Annual Report of Mie Hamajima Fisheries Experimental Station FY1981, pp. 1–43 (in Japanese).

Mori, K. 1999. The present situation of self-pollution of oyster culture areas and some possible measures to cope with this problem. *Suisanzoshoku* **47**: 173–180 (in Japanese with English abstract).

Ohyama, H., Kitadai, Y. and Kadowaki, S. 2005. Production of cultured *Laminaria japonica* and its nitrogen and phosphate uptake in a coastal fish farm, Yatsushiro Sea. *Memoirs of the Faculty of Fisheries, Kagoshima Univ.* **54**: 29–34 (in Japanese with English abstract).

Pawar, V., Matsuda, O., Yamamoto, T., Hashimoto, T. and Rajendran, N. 2001. Spatial and temporal variations of sediment quality in and around fish cage farms: a case study of aquaculture in the Seto Inland Sea, Japan. *Fish. Sci*. **67**: 619–627.

Pereira, R., Kraemer, G., Yarish, C. and Sousa-Pinto, I. 2008. Nitrogen uptake by gametophytes of *Porphyra dioica* (Bangiales, Rhodophyta) under controlled-culture conditions. *Eur. J. Phycol*. **43**: 107–118.

Rajendran, N., Yoshinouchi, H. and Matsuda, O. 1999. Short-term changes in sedimentary microbial communities from coastal aquaculture areas. *Fish. Sci*. **65**: 57–62.

Sakami, T., Abo, K., Takayanagi, K. and Toda, S. 2003. Effects of water mass exchange on bacterial communities in an aquaculture area during summer. *Estuar. Coast. Shelf Sci*. **56**: 111–118.

Sasaki, R., Oshino, A. and Kikuchi, R. 2002. Aggregative distribution of benthic animals in conjunction with environmental conditions below coho salmon culture-pen. *Miyagi Pref. Rep. Fish. Sci*. **2**: 17–26 (in Japanese with English abstract).

Sasaki, R. and Oshino, A. 2004. Environmental conditions relevant to aggregative distribution of macrobenthos below coho salmon culture cage. *Bull. Fish. Res. Agency* **Suppl 1**: 19–31.

Songsangjinda, P., Matsuda, O., Rajendran, N., Yamamoto, T. and Maeda, H. 1997. Uptake and release of particular materials by suspended oyster culture in Hiroshima Bay. *J. Fac. Appl. Biol. Sci., Hiroshima Univ*. **36**: 147–159.

Songsangjinda, P., Matsuda, O., Yamamoto, T., Rajendran, N. and Maeda, H. 2000. The role of suspended oyster culture on nitrogen cycle in Hiroshima Bay. *J. Oceanogr*. **56**: 223–231.

Sonoda, T., Nakao, S. and Takayasu, K. 2002. Polychaete community structure and its temporal change through last 20 years in the intensive scallop culture area, Saroma Lagoon, northern Japan. *Laguna* **9**: 19–30 (in Japanese with English abstract).

Suzuki, Y., Kametani, T. and Maruyama, T. 2004. Nutrient recovery from fish culture water using seaweed biofilter. *J. Japan Soc. Water Envir.* **27**: 817–824 (in Japanese with English abstract).

Takekawa, H., Ohta, H. and Igarashi, T. 1989. Occurrence of the sulfur bacteria *Beggiatoa* spp. in a coho salmon farm with reference to factors to induce the occurrence. *Bull. Kesennuma Miyagi Prefectural Fisheries Exper. Stn.* **8**: 82–93 (in Japanese).

Ueno, S., Nadaoka, S., Takayama, Y., Katsui, H. and Yamada, F. 2000. Field survey on growth process and organic loading of cultured pearl oyster in Ago Bay. *Proc. Coastal Engineer. JSCE* **47**: 1206–1210 (in Japanese).

Uede, T. 2008. Validity of acid volatile sulfide as environmental index and experiment for fixing its standard value in aquaculture farms along the coast of Wakayama Prefecture, Japan. *Nippon Suisan Gakkaishi* **74**: 402–411 (in Japanese with English abstract).

Uede, T. and Takeuchi, T. 2007. Postprandial changes in digesta, leftovers and feces, and their carbon and nitrogen contents in cultured red sea breams, *Pagrus major*. *Suisanzoshoku* **55**: 409–415 (in Japanese with English abstract).

Wakayama Research Center of Agriculture, Forestry and Fisheries. 2002. Report on the project for environmentally responsible, sustainable aquaculture in 2000. Annual Report of Fisheries Farming Laboratory, Wakayama Research Center of Agriculture, Forestry and Fisheries **33**: 79–115 (in Japanese).

Wakayama Research Center of Agriculture, Forestry and Fisheries, Oita Prefectural Agriculture, Forestry and Fisheries Research Center and Ehime Research Institute of Agriculture, Forestry and Fisheries. 2008. Year to year changes on AVS-S. Report on the project for promotion of sustainable aquaculture production and supply in 2007, pp. 26–29 (in Japanese).

Watanabe, T. 1991. Past and present approaches to aquaculture waste management in Japan, pp. 137–153 *in* Nutritional Strategies and Aquaculture Waste *edited by* C.B. Cowey and C.Y. Cho, University of Guelph, Guelph, Ontario, Canada.

Yagi, H., Ishida, H., Takahashi, A., Nadaoka, K., Tamura, H. and Kotani, M. 2004. Effect of fluid residence of nori culture facility on the circulation and transport of resuspended sediment. *Proc. Coastal Engineer. JSCE* **51**: 1026–1030 (in Japanese).

Yamamoto, T. 1992. Constant uptake of ammonium-N and nitrate-N by *Porphyra yezoensis* thalli. *J. Fac. Appl. Biol. Sci., Hiroshima Univ.* **31**: 155–159 (in Japanese with English abstract).

Yamamoto, T., Maeda, H., Matsuda, O. and Hashimoto, T. 2009. Effects of culture density on the growth and fecal production of oyster *Crassostrea gigas*. *Nippon Suisan Gakkaishi* **75**: 230–236 (in Japanese with English abstract).

Yokoyama, H. 2002. Impact of fish and pearl farming on the benthic environments in Gokasho Bay: Evaluation from seasonal fluctuation of the macrobenthos. *Fish. Sci.* **68**: 258–268.

Yokoyama, H. 2005. Benthos research expected by practical aquaculture farm, pp. 145–159 *in* Benthos and Fisheries *edited by* I. Hayashi and S. Nakao, Koseisha Koseikaku, Tokyo (in Japanese).

Yokoyama, H. 2010. Monitoring, assessment and management of fish farm environments in Japan. *Rev. Aquaculture* **2**: 154–165.

Yokoyama, H., Nishimura, A. and Inoue, M. 2002a. Influence of aquaculture and topographic conditions on the macrobenthos and the sediment in fish farms along the Kumano-nada coast. *Bull. Japanese Soc. Fish. Oceanogr.* **66**: 133–141 (in Japanese with English abstract).

Yokoyama, H., Nishimura, A. and Inoue, M. 2002b. Evaluation of fish farm environments by identifying community types of the macrobenthos. *Bull. Japanese Soc. Fish. Oceanogr.* **66**: 142–147 (in Japanese with English abstract).

Yokoyama, H., Inoue, M. and Abo, K. 2004. Estimation of the assimilative capacity of fish-farm environments based on the current velocity measured by plaster balls. *Aquaculture* **240**: 233–247.

Yokoyama, H., Abo, K. and Ishihi, Y. 2006. Quantifying aquaculture-derived organic matter in the sediment in and around a coastal fish farm using stable carbon and nitrogen isotope ratios. *Aquaculture* **254**: 411–425.

Yokoyama, H. and Ishihi, Y. 2010. Bioindicator and biofilter function of *Ulva* spp. (Chlorophyta) for dissolved inorganic nitrogen discharged from a coastal fish farm – potential role in integrated multi-trophic aquaculture. *Aquaculture* **310**: 74–83.

1.4 Republic of Korea

1.4.1 Overview

In Korea, seaweeds (laver, *Porphyra tenera* and sea mustard, *Undaria pinnatifida*) were the main cultured species from the 1960s to the 1970s. The focus of the 1970s to the early 1980s was primarily on the development of shellfish (oyster, *Crassostrea gigas* and ark shell, *Scapharca broughtonii*) culture. In the late 1980s, finfish culture had grown rapidly, and recently, it has begun to develop into integrated multi-trophic aquaculture (IMTA) to reduce environmental pollution in Korea (Fig. 1.4.1).

The production of marine aquaculture in Korea has increased 2.5 times in the last decade. Production in 2000 was 65 × 10^4MT and it grew to 136 × 10^4MT by 2010 (Fig. 1.4.2). In 2012, aquaculture production reached 137 × 10^4MT; the portion of finfish produced was 7.1%, shellfish was at 26%, and seaweed was at 65.5% (Fig. 1.4.3). Regarding the monetary value of aquaculture production in 2010, finfish accounted for 53.6%, shellfish for 24.8% and seaweed was at 18.3% (Fig. 1.4.4). Regional production comparisons show that the productivity in the southern sea of Korea is the highest at 91.9%, the eastern sea is at 1.7% and the western sea is at 6.4%. Thus the production in the southern sea is the largest in Korea (Fig. 1.4.5).

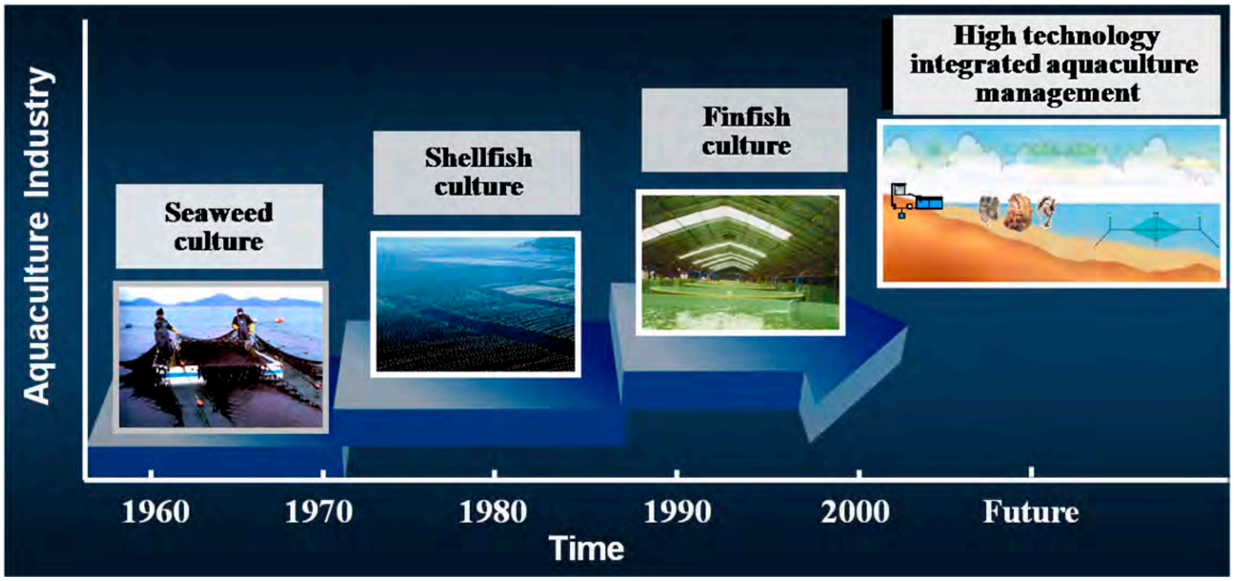


Fig. 1.4.1 History of aquaculture in Korea.

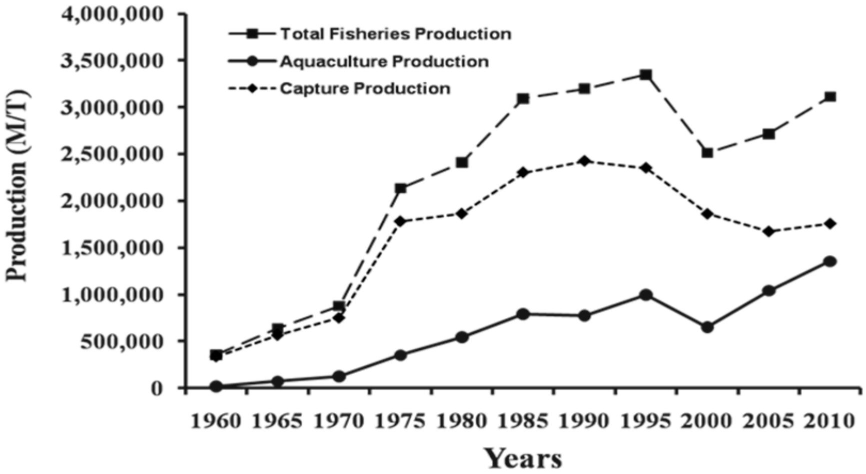


Fig. 1.4.2 Fisheries production of Korea.

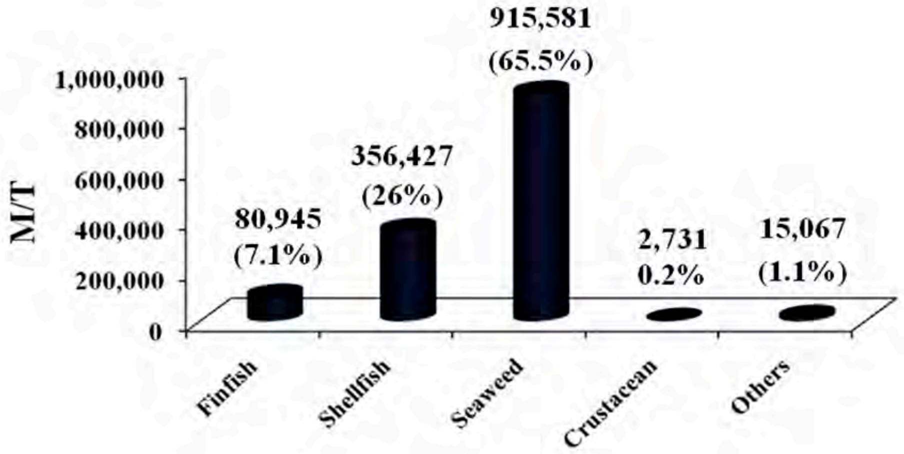


Fig. 1.4.3 Aquaculture production by cultured class in Korea (in 2010).

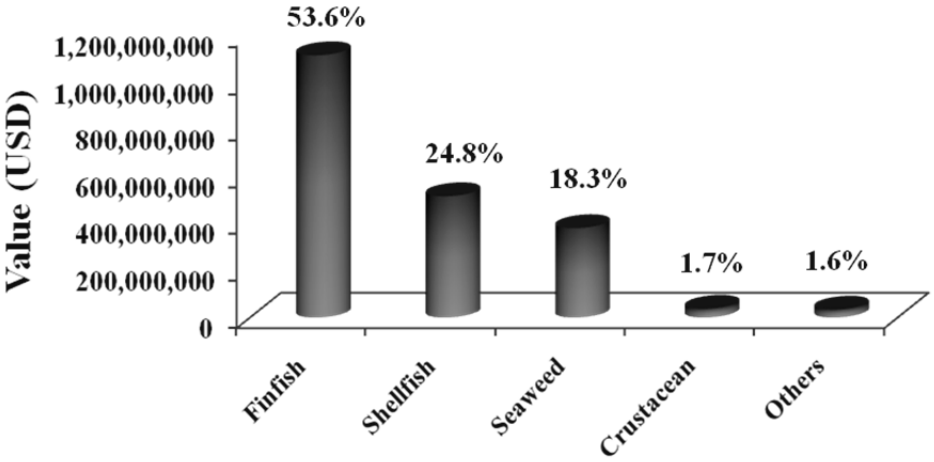


Fig. 1.4.4 Aquaculture production value by cultured class in Korea (in 2010).

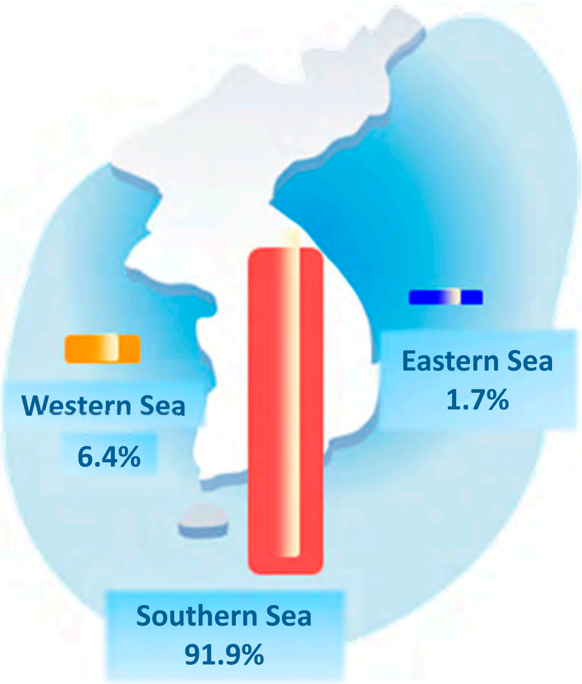


Fig. 1.4.5 Aquaculture production by region in Korea (in 2010).

Fig. 1.4.6 Main culture species in Korea.

1.4.2 Fish Culture

Olive flounder (*Paralichthys olivaceus*), black rockfish (*Sebastes schlegeli*) and red sea bream (*Pagrus major*) are the main cultured species in Korea (Figs. 1.4.6 and 1.4.7 and Table 1.4.1). Since 2005, a submerged net cage system in the country's offshore side is being used to reduce the impacts (eutrophication of nearshore due to intensive culture), and also to develop new cultured species of high value like bluefin tuna (*Thunnus orientalis*).

Table 1.4.1 Aquaculture production of marine finfish in Korea (in 2010).

Species	Production (M/T)
Olive flounder	41,897
Black rockfish	20,623
Red sea bream	6,354
Mullet	4,773
Others	7,298
Total	80,945

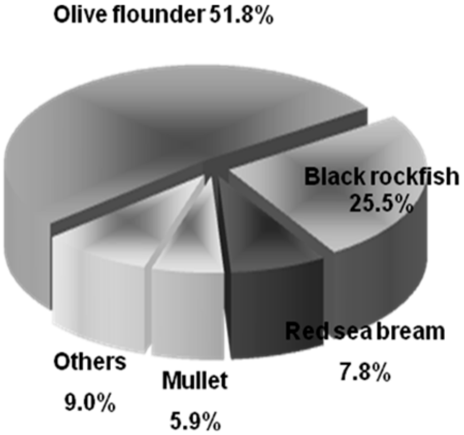


Fig. 1.4.7 Aquaculture production percentage of marine finfish in Korea (in 2010).

Near-field effects

Culture of finfish is mostly performed in land-based culture systems, cage culture systems and re-circulation systems. To culture fish, feed such as extruded pellets (EP), moist pellets (MP), and raw fish are used. Organic matter (uneaten feed and feces) from fish culture farms that are released into the coastal waters have been considered to be one of the major factors disturbing the benthic ecosystem (Jung *et al.*, 2002; Jung *et al.*, 2007). Organic matter causes eutrophication in culture farms, gathers on the bottom as sludge, and can cause hypoxia (Yoon *et al.*, 2007). Therefore, the southern coastal waters, where the largest aquaculture production in Korea can be found, frequently experiences harmful algal blooms (HABs) and as a result, there have been mass mortalities in the area. In view of chemical effects, organic matter changes occur in the levels of oxidation-reduction potential (ORP), acid volatile sulfides (AVS), chemical oxygen demand (COD), concentration of carbon (C) and nitrogen (N) in the sediments beneath finfish farms and in the surrounding areas. ORP has the tendency to increase with horizontal distance from net cage farms. AVS, COD values and concentrations of C and N represent an opposite tendency to ORP, decreasing farther from culture farms. All values of ORP, AVS, COD, C and N are significantly different in areas 15–20 m away from the culture farms (Kwon *et al.*, 2005).

Food waste is the main source of solid depositions in marine cage fish farms. In order to minimize solid deposition, it is necessary to increase the efficiency of the food uptake. Based on the results of several experiments, if the percentage of food waste is decreased to about 10%, then the solid depositions could decrease up to 50%. In addition, it was reported that if farmers use EP as food instead of MP and fish trash, solid deposition could decrease by 57%. Also, several studies have reported that the cage facility to the licensed area ratio can be decreased to less than 5% to minimize sediment pollution (Kwon *et al.*, 2005). From a biological effects standpoint, the number of dominant species, abundance, and diversity of benthic macrofaunal communities change with the distance from the fish cages (Jung *et al.*, 2002; Jung *et al.*, 2007). In regions that are highly enriched with organic materials, a zone is observed with low species diversity and density, dominated by the opportunistic polychaete *Capitella capitata*. On the other hand, the regions farthest from the cage culture (over 30 m) are observed to have the highest number of species and a higher density level (Lee *et al.*, 2004).

Far-field effects

The data acquired from benthic interaction with aquaculture activities in Korea is insufficient because of the limited time frame studied. We are currently performing research on the development of culture technology for bluefin tuna such as seedling production, appropriate feed, facilities, reasonable sinking depth when HABs come in from the offshore areas, *etc*. (Shin *et al.*, 2005; Ji *et al.*, 2008; Cho and Hwang, 2010).

1.4.3 Shellfish Culture

The main cultured species of shellfish in Korea are Pacific oysters (*Crassostrea gigas*), mussels (*Mytilus edulis*), Manila clams (*Ruditapes philippinarum*) and abalone (*Haliotis discus hannai*) (Table 1.4.2 and Fig. 1.4.8). The methods of shellfish culture used are hanging culture, net cage culture and on-bottom culture. Shellfish culture has less effect on the benthic environment when compared to finfish cultures because no feed is added to the environment, but due to intensive cultures and repeated cultivation, shellfish cultures can initiate the deterioration of the benthic environment. These changes (deterioration) lead to outbreaks of disease, and curtail the production of shellfish farms.

Table 1.4.2 Aquaculture production of shellfish in Korea (in 2010).

Species	Production (M/T)
Oyster	267,690
Sea mussel	55,366
Cockles	23,309
Abalone	6,226
Others	3,836
Total	356,427

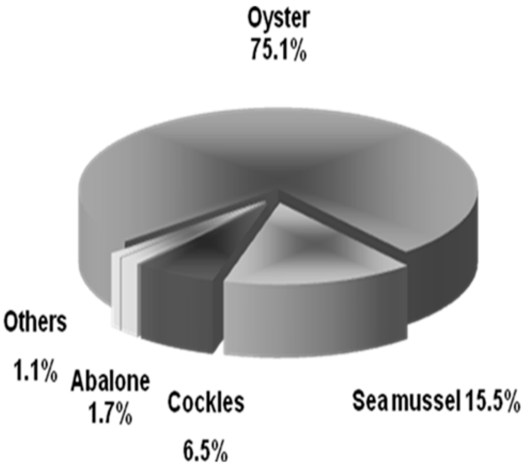


Fig. 1.4.8 Aquaculture production percentage of shellfish in Korea (in 2010).

Near-field effects

Cultured shellfish produce biodeposits in the form of feces and pseudofecal pellets that settle on the sediment. This organic waste and debris can accumulate in the sediment below shellfish cultures and potentially lead to organic enrichment and even eutrophication (Lim *et al.*, 1992; Kang *et al.*, 2002). Further, the cleaning of biofouling organisms from cultured shellfish may accumulate beneath the lease. This process leads to reduced oxygen content, increased nutrient loads (TOC (total organic carbon) and AVS) and alters the associated benthic macrofauna communities (Jelbart *et al.*, 2011). The phenomenon is more pronounced at farming stations in the inner bays (Yoon *et al.*, 2009; Cho *et al.*, 2010). Changes in benthic macrofauna may include a decrease in population and lower species richness (Park and Yi, 2002; Jeong and Cho, 2003; Lim *et al.*, 2007).

Cultured ark shells are harvested with a hooked dredge which is placed onto the sediment in springtime. The activity stirs the upper and lower sediment layers and destroys productive benthic habitats. Therefore, the spatial distribution of polychaetes may be closely related to the sedimentary disturbance produced during the selection of shells for harvesting in spring (Kang *et al.*, 2002).

Far-field effects

There is little information on far-field effects and benthic interaction from aquaculture activities in Korea.

1.4.4 Marine Algae Culture

Sea mustard (*Undaria pinnatifida*), kelp (*Laminaria japonica*) and laver (*Porphyra tenera)* are the main cultured seaweeds in Korea (Table 1.4.3 and Fig. 1.4.9). Originally, the aim of marine algae culture was to increase food production in Korea. Now, its main purpose is to enlarge the feedstock production of bio-fuel and medical supplies (Imbs *et al.*, 2009; Cabrita *et al.*, 2010; Bae *et al.*, 2011). Marine algae are important as food sources, bioremediators, and habitat for marine organisms and are a major part of aquaculture in Korea.

Table 1.4.3 Aquaculture production of marine algae in Korea (in 2010 year).

Species	Production (M/T)
Sea mustard	403,551
Kelp	248,873
Laver	231,842
Fusiforme	21,184
Others	10,131
Total	915,581

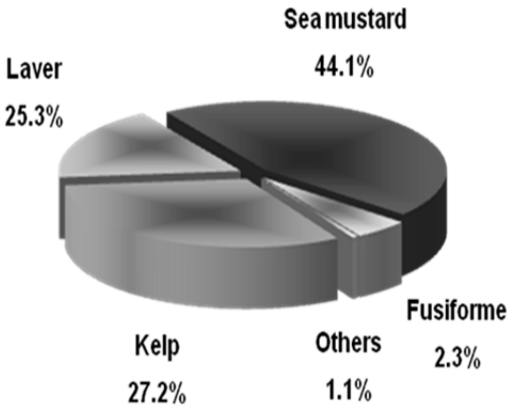


Fig. 1.4.9 Aquaculture production percentage of marine algae in Korea (in 2010).

Near-field effects

Marine algae are known to act as a biofilter against nutrient-rich effluent in seaweed-based integrated aquaculture systems. Kang *et al.* (2009) evaluated the bioremediation capacity of *Porphyra yezoensis*. They confirmed the potential role of *P. yezoensis* in removing around 43% of the ammonium from effluents. Hernandez *et al*. (2002) and Jones *et al*. (2001) reported that *Enteromorpha* sp. and *Gracilaria* sp. have a NH_4^+ filtration efficiency of over 80%. In the past, *Porphyra* sp. was the most popular species in Korea for reducing the risk of eutrophication but recently many experiments are evaluating *Undaria* sp. and *Laminaria* sp. in seaweed-based integrated aquaculture systems to remove or reduce mass nutrient sources.

Higher productivity and structural components of seaweed beds increase habitat complexity and provide habitat for marine animals. Therefore, to rehabilitate the impacted areas, artificial seeweed beds have been put into place. Kim and Kwak (2009) reported the results of monitoring benthic communities on artificial seaweed beds and concluded that plantation of marine algae (*Ecklonia stolonifera*) has contributed to the restoration of habitats for benthic communities in impacted areas.

Far-field effects

There is little information on far-field effects and benthic interaction from aquaculture activities in Korea.

1.4.5 Integrated Multi-Trophic Aquaculture

Before the introduction of the Integrated Multi-Trophic Aquaculture (IMTA) concept, polyculture was already explored in Korea. The National Fisheries Research and Development Institute (NFRDI) of Korea had already set up guidelines for polyculture (Anon., 1994). Examples include *Porphyra tenera* and short necked clams (*Ruditapes philippinarum*) or surf clams (*Mactra veneriforms*); *Laminaria japonica* and sea squirt (*Halocynthia roretzi*); *Undaria pinnatifida* or *L. japonica* and abalone (*Haliotis discus hannai*); and *Hizikia fusiformis* and abalone. These polycultures were aimed at yielding high productivity in limited areas. In the 1990s, finfish and shrimp cultures increased dramatically. During this period, a change in the concepts and strategies of integrated culture were required because of the effluents from these organisms. Therefore, the IMTA concept of eco-friendly aquaculture was introduced in the 2000s. As an integral part of IMTA, deposit feeding sea cucumbers (*Stichopus japonicus*) were cultured along with finfish and shellfish to improve the sediment environment (Kang *et al.*, 2003; Zhou *et al.*, 2006; Slater and Jeffs, 2010).

1.4.6 Conclusions

Aquaculture is a very important industry in Korea. Aquaculture-related activities may generate significant nutrient loading of coastal waters that can lead to eutrophication. Solutions to the problem of eutrophic effluent, addressing both ecological and economical issues, are the development of IMTA and offshore culture, but these technologies are in the early stages of growth in Korea. To popularize these technologies in the aquaculture industry, we still face several challenges. In the case of offshore culture, we need to investigate and develop the following:

- Specialized offshore cages for the southern coast of Korea, and bottom-dwelling fish;
- Super high-value candidate fish species for offshore aquaculture;
- An automatic system of feeding, monitoring, swimming activity, *etc*.;
- Sorting, thinning, net cleaning, and harvesting;
- A better understanding of the dynamics of cultured species.

In the case of IMTA, we need to establish guidelines for appropriate locations and species, and when an outbreak of disease occurs, a quarantine between cultured species will be needed. We are also considering joining aquaculture and tourism, and are continuing to investigate the interactions and effects of culture with the environment (including the benthic environment).

1.4.7 References

Anonymous. 1994. Studies on the development of polyculture system in the coastal waters of Korea – Final report. National Fisheries Research and Development Institute, 570 pp. (in Korean with English summary).

Bae, Y.J., Ryu, C., Jeon, J.K., Park, J., Suh, D.J., Suh, Y.W., Chang, D. and Park, Y.K. 2011. The characteristics of bio-oil produced from the pyrolysis of three marine macroalgae. *Biosource Technol*. **102**: 3512–3520.

Cabrita, M.T., Vale, C. and Rauter, A.P. 2010. Halogenated compounds from marine algae. *Mar. Drugs* **8**: 2301–2317.

Cho, E.S. and Hwang, H.K. 2010. Bluefin tuna (*Thunnus thynnus* L.) aquaculture in Yokjido, Tongyeong: Fluctuation of phytoplankton and reasonable sinking depth in floating cage. *J. Korean Soc. Mar. Environ. Safety* **16**: 381–386 (in Korean with English summary).

Cho, Y.S., Hong, S.J., Park, S.E., Jung, R.H., Lee, W.C. and Lee, S.M. 2010. Application of ecological indicator to sustainable use of oyster culture grounds in Geoje Hansan bay, Korea. *Soc. Mar. Environ. Safety* **16**: 21–29 (in Korean with English summary).

Hernández, I., Martínez-Aragón, J.F., Tovar, A., Pérez Lloréns, J.L. and Verara, J.J. 2002. Biofiltering efficiency in removal of dissolved nutrients by three species of estuarine macroalgae cultivated with sea bass (*Dicentrarchus labrax*) waste water. 2. Ammonium. *J. Appl. Phycol*. **14**: 375–384.

Imbs, T.I., Krasovskaya, N.P., Ermakova, S.P., Makarieva, T.N., Shevchenko, N.M. and Zvyagintseva, T.N. 2009. Comparative study of chemical composition and antitumor activity of aqueous-ethanol extracts of brown algae *Laminaria cichorioides*, *Costaria costata*, and *Fucus evanescens*. *Biochem*. **35**: 164–170.

Jelbart, J.E., Schreider, M. and Macfarlane, G.R. 2011. An investigation of benthic sediments and macrofauna within pearl farms of Western Australia. *Aquaculture* **319**: 466–478.

Jeong, W.G. and Cho, S.M. 2003. The physiochemical characteristics of seawater and sediment of marine shellfish farm in Jindong bay. *Korean J. Malacol*. **19**: 161–169 (in Korean with English summary).

Ji, S.C., Takaoka, O., Takii, K., Jeong, G.S. and Han, S.J. 2008. Seedling production of the Pacific blue fin tuna *Thunnus orientalis*. *J. Aquaculture* **21**: 272–277.

Jones, A.B., Dennison, W.C. and Preston, N.P. 2001. Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. *Aquaculture* **193**: 155–178.

Jung, R.H., Lim, H.S., Kim, S.S., Park, J.S., Jeon, K.A., Lee, Y.S., Lee, J.S., Kim, K.Y. and Go, W.J. 2002. A study of the macrozoobenthos at the intensive fish farming grounds in the southern coast of Korea. *J. Korean Soc. Oceanogr*. **7**: 235–246 (in Korean with English summary).

Jung, R.H., Yoon, S.P., Kwon, J.N., Lee, J.S., Lee, W.C., Koo, J.H., Kim, Y.J., Oh, H.T., Hong, S.J. and Park, S.E. 2007. *J. Korean Soc. Oceanogr*. **12**: 159–169 (in Korean with English summary).

Kang, C.K., Baik, M.S., Kim, J.B. and Lee, P.Y. 2002. Seasonal and spatial distribution of soft-bottom polychaetes in Jinju bay of the southern coast of Korea. *J. Korean Fish. Soc*. **35**: 35–45 (in Korean with English summary).

Kang, K.H., Kwon, J.Y. and Kim, Y.M. 2003. A beneficial coculture: Charm abalone *Haliotis discus hannai* and sea cucumber *Stichopus japonicus*. *Aquaculture* **216**: 87–93.

Kang, Y.H., Park, S.R., Oak, J.H., Seo, T.H., Shin, J.A. and Chung, I.K. 2009. Physiological responses of *Porphyra yezoensis* Ueda (Bangiales, Rhodophyta) exposed to high ammonium effluent in a seaweed-based integrated aquaculture system. *J. Fish. Sci. Technol*. **12**: 70–77.

Kim, J.M. and Kwak, S.N. 2009. Monitoring in succession of benthic communities on artificial seaweed beds in the slag dumping area. *J. Korean Soc. Mar. Environ. Engineer*. **12**: 157–164 (in Korean with English summary).

Kwon, J.N., Jung R.H., Kang, Y.S., An, K.H. and Lee, W.C. 2005. Environmental management of marine cage fish farms using numerical modeling. *J. Korean Soc. Oceanogr*. **10**: 181–195 (in Korean with English summary).

Lee, J.S., Jung, R.H., Kim, K.H., Kwon, J.N, Lee, W.C., Lee, P.Y., Koo, J.H. and Choi, W.J. 2004. An evaluation of the environmental effects of marine cage fish farms: I. Estimation of impact region and organic carbon cycling in sediment using sediment oxygen consumption rates and macrozoobenthos. *J. Korean*

Soc. Oceanogr. **9**: 30–39 (in Korean with English summary).

Lim, H.S., Choi, J.W., Je, J.G. and Lee, J.H. 1992. Distribution pattern of macrozoobenthos at the farming ground in the western part of Chinhae Bay. Korea. *Bull. Korean Fish. Soc.* **25**: 115–132 (in Korean with English summary).

Lim, K.H., Shin, H.C., Yoon, S.M. and Koh, C.H. 2007. Assessment of benthic environment based on macrobenthic community analysis in Jinhae bay, Korea. *J. Korean Soc. Oceanogr*. **12**: 9–23 (in Korean with English summary).

Park, H.S. and Yi, S.K. 2002. Assessment of benthic environment conditions of oyster and mussel farms based on macrobenthos in Jinhae bay. *Korean Soc. Mar. Environ. Engineer*. **5**: 68–75 (in Korean with English summary).

Shin, J.K., Jeong, S.J. and Yoon, J.H. 2005. A study on the development of the aquaculture fishcage for the open sea. *J. Navigation Port Res*. **4**: 285–290 (in Korean with English summary).

Slater, M.J. and Jeffs, A.G. 2010. Do benthic sediment characteristics explain the distribution of juveniles of the deposit-feeding sea cucumber *Australostichopus mollis*? *J. Sea Res*. **64**: 241–249.

Yoon, S.P., Jung, R.H., Kim, Y.J., Kim, S.S., Lee, J.S., Park, J.S., Lee, W.C. and Choi, W.J. 2007. Characteristics of benthic environment and polychaete communities of Gamak bay, Korea. *J. Korean Soc. Oceanogr*. **12**: 287–304 (in Korean with English summary).

Yoon, S.P., Jung, R.H., Kim, Y.J., Hong, S.J., Oh, H.T. and Lee, W.C. 2009. Spatio-temporal changes in macrobenthic community structure and benthic environment at an intensive oyster culturing ground in Geoje-Hansan bay, Korea. *J. Korean Soc. Oceanogr.* **14**: 213–228 (in Korean with English summary).

Zhou, Y., Yang, H., Liu, S., Yuan, X., Mao, Y., Liu, Y., Xu, X. and Zhang, F. 2006. Feeding and growth on bivalve biodeposits by the deposit feeder *Stichopus japonicus* Selenka (Echinodermata: Holothuroidea) co-cultured in lantern nets. *Aquaculture* **256**: 510–520.

1.5 Russia

1.5.1 Overview

At present, the volume of aquaculture products in Russia is comparatively small – about 115 thousand tons (value of 6.7 billion rubles), 101 and 105 thousand tons of which, respectively, in 2002 and 2006 represented freshwater fish farming. Aquaculture production is about 5% of Russia's capture fishery. The conditions for development of marine aquaculture exist in three of seven federal districts of Russia. Most territory of Russia is located in zones not favorable for commercial cultivation of aquatic organisms, but there are areas where the development of marine aquaculture may be promising (Makoedov and Kozhemyako, 2005), such as the Far East. Seas in the northwest of Russia are also promising for the development of aquaculture of native cold-water fish. In the Barents and White seas, the potential production capacity of fish farming could reach 5 thousand tons per year. Coastal areas are promising for the cultivation of Atlantic salmon, codfish, flounder and others (Zhuravleva and Zenzerov, 1998; Larina and Zhuravleva, 2009).

Regular studies of the environmental interaction of aquaculture have not yet been carried out in Russia. However, in the areas where mariculture is developed, certain assessments of the changes near experimental or commercial aquaculture facilities have been made.

1.5.2 Fish Culture

There is no commercial marine fish rearing in Russia although successful research in this area was carried out 30–40 years ago. In the 1970s–80s, research on the breeding of salmon, both endemic species – Atlantic salmon *Salmo salar*, and Far Eastern species – humpback (pink) salmon *Oncorhynchus gorbusha* and coho salmon *Oncorhynchus kisutch*, was developed in the European part of Russia (Anokhina, 1997; Krutova, 1981).

In the Far East there are currently 46 salmon hatcheries that produced 700 million juveniles in 2006, most of which (87.5%) came from Sakhalin (Anon., 2010).

1.5.3 Shellfish Culture

Shellfish culture began to develop in Russia in the 1970s. During this period, the first scientific research was carried out and experimental marine farms were established. After a 10-year break in the 1990s related to social reconstruction in Russia, the number of mariculture farms began to increase. This was due, on the one hand, by increased demand for seafood and, on the other hand, by the considerable reduction of stocks of valuable species. The first successes contributed to further growth in the number of mariculture farms and volumes of products obtained. By 2009, the total annual production of mariculture in Primorye increased by a factor of 7; however, its volume remained less than 2 thousand tons. In the last 10 years (from 2001 through 2010), all marketable products of mariculture reached 10 thousand tons. The major share of this volume was represented by the scallop *Mizuhopecten yessoensis* followed by the mussel *Mytilus trossulus* and the Pacific oyster *Crassostrea gigas*.

In the last 10 years, operations related to the restoration of stocks and commercial cultivation of the sea cucumber (trepang) have been carried out, and three hatcheries for producing juveniles were established. Two of them are scientific-experimental hatcheries and one is an industrial hatchery with an output of about 10 million individuals. Beginning in 2005, hatchery-produced juveniles were grown on bottom plantations in marine farms. In 2009, more than 4 tons of the marketable products were obtained while, in 2010, the volume of marketable trepang products reached about 15 tons.

The carrying capacity of Peter the Great Bay (Sea of Japan) allows for expanding production of both bivalve mollusks and sea cucumbers. According to our estimates, about 100 thousand tons of bivalve mollusks could be produced per year within the coastal zone of the Bay. Since deep-water technologies are not used in the region so far, only the carrying capacity of the coastal zone to depths of 20 m was taken into account in this calculation. In order to produce 1,000 tons of marketable trepang products every year in Peter the Great Bay, up to 40 million hatchery-produced juveniles a year would need to be released.

Near- and far-field effects

In Russia, different methodical approaches have been used to evaluate the interaction between aquaculture and the environment. First of all, this is an evaluation of variations taking place in the pelagic and benthic ecosystems where the mariculture plantations are located. The results of studies from different regions of Russia are presented as examples below.

In the Sea of Japan (Peter the Great Bay), the cultivation of bivalve mollusks has been going on since the 1970s. In Alekseev bight, a farm for cultivation of the scallop *Mizuhopecten yessoensis* operated for 10 years. Over this period, the condition of the plankton and benthic communities was observed. In plankton, an abrupt decrease in the amount and change in the species composition of invertebrate larvae was found. The density of meroplankton in the bight was abnormally low during the years of the farm's existence and the number of echinoderm larvae was greatly reduced (at least 100 times). An increase in the quantity of larvae occurred only 2 years after the termination of the farm activity. After the liquidation of plantations in the bight, the quantity of epibiont larvae also decreased, but there was a significant increase in the quantity of echinoderm larvae which are most sensitive to organic loading (Maslennikov *et al.*, 1994). As a result of the ecological situation worsening in the bight during this period, a disturbance in the reproductive function was registered for two macrobenthic species – the sea urchin *Strongylocentrotus intermedius* and scallop *Mizuhopecten yessoensis* (Vashchenko *et al.*, 1993; Vaschenko *et al.*, 1997). Influenced by the aquaculture plantations of scallop cultivated within the water column, there was also a rise in the quantity of microorganisms in the surface ground layer and a reconstruction of the microbial community of bottom deposits which provided favorable conditions for the cultivation of the detritus feeding sea cucumber *Apostichopus japonicus* (Bregman, 1994).

In the Minonosok bight, carrying capacity calculations suggested that farmed areas should not exceed 4.5% of the bight water-surface area. However, scales of cultivation in the 1980s were more sizeable: the aquaculture facilities occupied about 20% of the water surface and the quantity of the mollusks cultivated was twice as large as the suggested values in some years. Studies carried out 10 years after the establishment of plantations showed that in the bight an accumulation of mollusk biodeposits and reduction in the total number of benthic species took place (Gabayev *et al.*, 1998).

Within the Russian zone of the Black Sea, studies were carried out in benthic areas near mussel plantations (Pereladov, 1987; Pereladov and Britaev, 1988). Long-term observations showed that species composition of the benthos has changed considerably: near the mussel plantations an increase in mollusk and polychaete species was observed, which is typical for areas with increased content of organic wastes. Yet, total biomass and benthos quantity did not change significantly. Silting under the mussel facilities resulted in an increase in the abundance of polychaetes and a reduction in mollusks. On one hand, a substitution of the native fauna occurred which is interpreted as a negative effect but, on the other hand, the food resources for commercially important fish has increased which could be viewed as prerequisites for increasing area productivity (Dushkina *et al.*, 1998).

Studies carried out near mussel plantations in the White Sea showed that a redistribution of organic substances took place in the pelagic and bottom areas in the immediate vicinity which, in turn, resulted in a change in community structure. Near the plantations, an abrupt reduction in the protein content was noted by Primakov *et al.* (2008) who attribute it to an increase in the relative share of bacteria present in the plankton. Plantations did not, however, have a pronounced effect on the quantity and biomass of zooplankton. An irregular distribution of deposits to the bottom across the area resulted in increases in the organic load and, in some cases, resulted in a degradation of the benthic communities (Primakov *et al.*, 2008).

In recent years, a quantitative assessment of the degree of organic pollution based on the value of the ground oxidation-reduction potential (Eh), reflecting the activities of chemical and biological oxidation, has been used. Variation of this index within the sediments suggests a change in the oxidizing conditions and availability of free oxygen. Observations made in sections under mussel plantations in the White Sea showed that, in circumstances where the oxygen is depleted by oxidation of organic substances, incoming deposits do not have time to be fully mineralized under low oxygen conditions. As the concentration of the organic matter in the sediment increases, changes in the benthic communities occur and several dominant species have been replaced by new ones (Primakov *et al.*, 2008).

In the eastern part of the Black Sea, an ecological assessment was used to determine the effect of a fish hatchery on the environment. Based on long-term field oceanographic observations, natural factors determining the delivery of organic matter and the intensity of its biogeochemical transformation, the condition of accumulated deposits, and water aeration on the coast within the Russian zone were described (Fashchuk *et al.*, 2007).

Further research on the characteristics determining the degree of organic loading and examination of biological carrying capacities is needed for efficient control of bivalve mollusk aquaculture. To this end, the structural and functional characteristics of plankton and benthos communities around mariculture farms and beyond their boundaries are now being studied.

1.5.4 References

Anokhina, V.S. 1997. Effect of incubation temperature on the rate of development, morphogenesis and exit of smolts in Atlantic salmon *Salmo salar* L. The First Congress of Russian Ichthyologists, *Tr. VNIRO*, Moscow, p. 263 (in Russian).

Anon. 2010. The outcome of salmon hatcheries in the Far East in 2005/2006 and 2006/2007. 2010. *Fisheries* **6**: 86–87 (in Russian).

Bregman, Y.E. 1994. Bioenergy food chain “clam-filter feeders – holothurian-feeders” in biculture. *Izv. TINRO* **113**: 5–12 (in Russian).

Dushkina, L.A., Lapshin O.M. and Pereladov, M.V. 1998. Interaction of aquaculture with the environment, pp. 295–315 *in* Biological Foundation of Mariculture *edited by* A. Dushinka, VNIRO, Moscow (in Russian).

Fashchuk, D.A., Muravjev, V.B. and Petrenko, O.A. 2007. Geographic-ecological assessment potential effect of mariculture on the coastal waters in the eastern part of the Black Sea. *Water Resources* **34**: 216–224 (in Russian).

Gabaev, D.D., Kucheryavenko, A.V. and Shepel, N.A. 1998. Anthropogenic eutrophication of Posiet Bay, Sea of Japan with mariculture facilities. *Mar. Biol.* **24**: 53–62 (in Russian).

Gavrilova, G.S. 1996. Abiotic factors for sea cucumber juveniles in hatchery, pp. 71–75 *in* Proceedings of The State and Prospects of Scientific and Practical Developments in Aquaculture, Rostov n/D.

Krutova, A.D. 1981. Cultivation of coho salmon in sea cages in the Arctic *in* Scientific and practical principles of aquaculture and fisheries in the coastal zone of the White and Barents Seas. *Tr. VNIRO* **45**: 122–129 (in Russian).

Larina, T.M. and Zhuravlev, N.G. 2009. The development of aquaculture fish in the Northlands. *Vestnik MGTU* **12**: 344–349 (in Russian).

Makoedov, A.N. and Kozhemyako, O.N. 2005. Foundations of fisheries policy in Russia. www.npacific.ru/np/library/publikacii/makoedov/04_1.htm.

Maslennikov, S.I., Korn, O.M., Kashin, I.A. and Martynchenko, U.N. 1994. Long-term changes in the number of larvae of benthic invertebrates in the Alekseev Bay of Islands Popov, Japan Sea. *Mar. Biol.* **20**: 107–114 (in Russian).

Pereladov, M.V. 1987. The dynamics of mollusks biocenoses in mussel farm areas, pp. 423–425 *in* Mollusks: Results and Prospects of Research. VNIRO (in Russian).

Pereladov, M.V. and Britaev, T.A. 1988. The impact of industrial cultivation of mussels on the benthos of Sudak Bay of the Black Sea. *Fisheries* **9**: 27–30 (in Russian).

Primakov, I.M., Ivanov, M.V., Lezin, P.A., Kulakovskii, E.E. and Sukhotin, A.A. 2008. Effect of aquaculture on benthic mussels and plankton communities in the White Sea. *Oceanology* **48**: 249–253 (in Russian).

Vaschenko, M.A., Zhadan, P.M., Karaseva, E.M. and Lukjanova, O.N. 1993. Reproductive function failure of the sea urchin *Strongylocentrotus intermedius* from polluted areas of Peter the Great Bay, Sea of Japan. *Mar. Biol.* **19**: 57–66 (in Russian).

Vaschenko, M.A., Syasina, I.G., Zhadan, P.M. and Medvedeva, L.A. 1997. Reproductive function state of the scallop *Mizuhopecten yessoensis* Jay from polluted areas of Peter the Great Bay, Sea of Japan. *Hydrobiologia* **352**: 231–240 (in Russian).

Zhuravleva, N.G. and Zenzerov, V.S. 1998. Ecomorphological Basis of the Aquaculture of Polar Region Fishes. Kolsky Scientific Center Russian Academy of Sciences, Murmansk, 374 pp. (in Russian).

1.6 United States of America

1.6.1 Overview

Commercial marine aquaculture on the west coast of the United States currently consists of estuarine culture of shellfish (mostly oysters, hardshell clams, geoducks, and mussels), net pen culture of finfish (mostly salmonids), and land-based aquaculture of abalone, marine algae, several species of finfish and larval shellfish. To date, commercial marine finfish culture has been almost entirely carried out in open water net pens that are anchored in protected nearshore waters (primarily Puget Sound and the Columbia River in Washington State, but there are small operations for several species in Hawaii and experimental operations for white sea bass in California). Shellfish culture includes off-bottom raft culture of oysters and mussels, particularly in deeper estuarine water, long-line oyster culture, and on-bottom oyster, clam and geoduck aquaculture in intertidal areas, including the use of predator netting and/or bags. Integrated multi-trophic marine aquaculture appears to hold promise, but is only now being experimented with and has not yet been practiced at a commercial scale along the U.S. west coast (Rensel *et al.*, 2011). Similarly, while the aquaculture industry is poised to take advantage of very productive offshore coastal waters, there has been limited interest, and that industry is in its infancy on the west coast of the United States (Cheney *et al.*, 2010).

Environmental interactions between marine aquaculture and the environment are actively being studied by academic and government scientists in the United States. Several recent reviews outline the existing state of knowledge for shellfish aquaculture (Dumbauld *et al.*, 2009; NRC, 2010) and a review of the effects and risk analysis for salmon aquaculture was completed by Nash (2003, 2005). The brief analysis below is largely taken from these reviews.

1.6.2 Fish Culture

The primary finfish species under culture along the U.S. west coast is Atlantic salmon (*Salmo salar*) which have been reared in net pens in Washington State since the mid-1970s when stocks from Maine were brought to the NOAA Manchester Aquaculture Laboratory in Puget Sound for stock conservation rearing purposes. Commercial rearing of Atlantic salmon commenced in the 1980s in both Maine and Washington State. In 2011 there were 26 finfish leases in Maine and eight in Washington State. The finfish net pen industry is approximately an order of magnitude (10×) smaller than that in Canada (Amos and Appleby, 1999). Although the extent of the changes are always site dependent, the environmental effects of U.S. net pen aquaculture facilities are generally equivalent to those that occur in very similar environments in British Columbia where much of the research has been conducted.

Near-field effects

The environmental effects of marine fish culture on the west coast of the United States have been examined and a risk assessment document compiled (Nash *et al.*, 2005). The extent of near-field effects depends on the density and size of the fish being raised, the quantity of feed being used, management practices like cleaning the nets, and perhaps most importantly, the characteristics of the culture site. Both Washington State and Maine have minimum net pen site flow and depth requirements and other aquatic bedland standards dealing with allowable practices, avoidance of special habitats, and related considerations. Models like DEPOMOD were initially developed and used to predict organic matter deposition, given the appropriate site conditions, and used to develop performance measures (Cromey *et al.*, 2002). While these models were reasonably accurate for simulating bottom effects in slow velocity current conditions, they did not accurately predict organic waste distribution and assimilation at sites where currents were stronger and where solid waste particles that settled to the bottom were re-suspended (Chamberlain and Stucchi, 2007).

Subsequently, a model with user-selectable parameters such as separate feed or fecal settling rates and an adjustable resuspension routine was developed for both benthic (sediment organic carbon, sulfide, oxygen) and water column effects (ammonia/urea nitrogen, phytoplankton, zooplankton and dissolved oxygen) and applied to both near- and far-field applications (Rensel *et al*., 2006; Rensel *et al*., 2007; Kiefer *et al*., 2011; O'Brien *et al*., 2011). This model runs within a unique three-dimensional geographical information system (GIS) to allow the user to visualize effects that occur in time and space over the GIS domain. The model uses local (current meter) information or can couple to regional ocean models to simulate effects over large distances and multiple farms (discussed below).

Physical changes

Aquaculture net pen structures alter water column flow immediately around the pens by diverting some of the flow. Deposition of feces and unconsumed food may change the physical characteristics of the benthos, but usually only in soft bottom areas that have weak current flows where sediment grain size may become further dominated by fine particles. If the bottom previously consists of large grain size or rocky substrate, indicating an erosional substrate and strong currents, net pens are unlikely to cause physical changes in the sea bottom near or remote from the pens. Though marine net pen farms in the United States were often initially located in poorly flushed bays and backwaters, they have now been removed from such areas or relocated to more suitable channel areas known to be less nutrient sensitive due to problems with naturally-occurring harmful algal blooms and promulgation of regulations limiting fish farm size in such backwaters.

Chemical changes

Finfish waste and excess food result in nutrients being added to the water column and benthos (Pearson and Rosenberg, 1978; Brooks and Mahnken 2003a; Brooks *et al*., 2003). Significant measurable increases in dissolved nitrogen at Atlantic salmon farms and areas more than a few tens of meters downstream of net pen areas have only infrequently been observed in the U.S. Pacific Northwest (Rensel, 1989; WDF, 1990). As a result of 10 years of monitoring and a trend to site farms in less nutrient sensitive areas, the water column nutrient requirement was removed from net pen permits in Washington State (Rensel, 2001; Brooks and Mahnken, 2003a). In poorly flushed areas, the water column dissolved oxygen concentration could also be reduced, but this rarely occurred at U.S. salmon farms except due to natural conditions associated with the upwelling of nutrient-rich water or winds bringing deep anoxic water to the surface in fjords. Chlorophyll content in the water was not affected by fish farms in Puget Sound because nutrients are naturally replete and generally do not limit phytoplankton growth there, and phytoplankton growth rate is slower than flushing time (Rensel Associates and PTI Environmental Services, 1991). Reviews of the industry in British Columbia and elsewhere suggest that only about 3% of dry feed is lost to the environment and that fish feces contribute much more substantially to total volatile solids (TVS, 4 kg $m^{-2}y^{-1}$) which, in turn, are directly related to increased sulfides and low dissolved oxygen in the sediments. The magnitude of the change in all of these parameters, as well as remediation or recovery after fallowing, has been associated with water depth and current speed at the farm site (Brooks *et al*., 2003; Brooks *et al*., 2004). Zinc, an essential vertebrate nutrient added to fish food, and copper, which is used in anti-fouling treatment on nets, have been shown to enhance the concentration of these metals in the sediments, but their bioavailability is reduced to low levels by sulfides in the sediment (Brooks and Mahnken, 2003b). The form of zinc added to feed is now zinc sulphate which has also reduced buildup in the sediments.

Biological changes

When they occur, chemical and physical changes to the sediments described above cause changes to the benthic infauna community that have been well characterized for any kind of organic enrichment to soft sediment communities (Pearson and Rosenberg, 1978). These include reduced species diversity, a change in trophic structure from a mix of benthic filter and deposit feeders to dominance by deposit feeders, changes in species composition to those that tolerate disturbance, sulfides and low oxygen (*e.g.*, opportunistic polychaetes like *Capitella* and *Schistomeringos*, and *Ophrytrocha*), and finally a shift towards anaerobic microbial communities (*Desulfovibrio* and *Beggiatoa* spp. mats). Since the amount of deposition and chemical changes depend on net pen site location, size and fish farming practices, these community changes also depend on these parameters and some sites do not conform to the usual pattern (Brooks *et al*., 2003; Brooks *et al*., 2004).

Other potential biological effects of finfish culture that have been of concern include the transfer of fish disease organisms and biological interactions of escaped fish with wild populations and other wildlife. Concerns over disease transfer include either introducing a new disease to the system or enhancing disease transfer by placing fish in dense culture. Despite periodic reports of diseases associated with introduced fish elsewhere, and historically common introductions into U.S. waters, no new Atlantic salmon stocks or eggs have been legally moved into Washington State waters since 1991 and similar regulations prevent transfer elsewhere. It has also been shown that the level of most pathogens in water within a few meters of net pens is not enough to enable disease transmission from caged fish to those outside the pens.

Parasitic copepods or sea lice are one possible exception that have been studied in some detail. These crustaceans have free living planktonic larval stages that can infect nearby hosts and are present on both cultured Atlantic salmon and native Pacific salmon. They have caused problems for farmed fish in British Columbia in the past, but that was prior to proactive management which involves monitoring, treatment, if necessary, when thresholds of infection are breached, and a number of best management practices to reduce the risk. There is an extensive debate over whether sea lice from fish farms in British Columbia infect wild fish, especially migrating juvenile pink and sockeye salmon. Some authors have constructed population models forecasting salmon extinction in British Columbia within four generations (Krkosek *et al.*, 2009). However, some of the largest runs in history occurred subsequent to these forecasts. Sea lice abundance on juvenile wild salmon and herring is higher in areas with active farms than areas without salmon farms (*i.e.*, the southern Strait of Georgia, Morton *et al*., 2011; Saksida *et al.*, 2011). Reduced salinity of seawater may explain the low prevalence of sea lice in Washington State farm-reared salmon, where there are only eight active and widely separated farms. Salmon have been reared in experimental and commercial cages in Puget Sound and Juan de Fuca Strait for over 40 years with no observed sea lice outbreak that required treatment using thresholds established in British Columbia. Most juvenile wild salmon outmigrate during mid-spring to early summer when salinity is reduced due to annual peaks in river discharge, a fact that further reduces risk in Puget Sound. Sea lice infestations can be treated with a parasiticide which decreases the infection level on farms and in wild fish and there has been considerable debate as to their effects on wild salmon (Brooks and Jones 2008; Brooks, 2009; Krkosek *et al*., 2009; Marty *et al*., 2010).

A very small percentage of farmed Atlantic salmon has escaped over the lifetime of culture operations on the U.S. west coast, but it has been shown that there is little risk of several potential interactions with native species in the local ecosystem including (1) hybridization with Pacific salmon, (2) colonization of salmon habitat, (3) competition for food and (4) predation on other native species (Nash 2003; Waknitz *et al*., 2003).

Far-field effects

The extent of far-field effects of finfish culture is directly related to the size of the operation, the physical and hydrographic characteristics of the culture site, and the ambient water quality conditions of the receiving waters. Deposition of volatile organic solids from feed and feces to the bottom, and resulting changes in the benthic community, have been shown to extend up to 225 m from one particularly large net pen operated several decades ago (Weston 1990; Brooks and Mahnken 2003a). However, current regulations in Washington State and Maine prohibit any adverse effect more than 30 m distant from commercial net pen perimeters. Thus benthic effects are only considered under the near-field category discussed above. Water column effects of commercial fish net pen operations have been repeatedly measured in Maine (dissolved oxygen) and Washington State (dissolved oxygen and dissolved inorganic nitrogen). Dissolved oxygen effects are routinely measurable immediately downstream of the net pens but are restricted to a minimal distance (*i.e.*, < 30 m) and extent (*i.e.*, 0.2 mg/L depletion) relative to ambient waters (WDF, 1990, Normandeau and Associates and Battelle, 2003). Dissolved nitrogen (from ammonia excretion) flux from fish farms was measured at salmon net pen sites in Washington State and found to be similar to laboratory measurements in most cases and insignificant ecologically, as all net pens are purposely located in areas with high background concentrations of nitrogen from natural oceanic upwelling with a low probability of effects on algae or harmful algae (Rensel Associates and PTI Environmental Services, 1991; Mackas and Harrison, 1997; Anderson *et al*., 2008). These effects are also considered near field due to the few numbers of fish farms that are spatially separated. If there were numerous fish farms in a relatively small area, cumulative effects could occur and constitute "far-field" changes that would have to be considered as a carrying capacity issue. Carrying capacity for water column or benthic effects is generally not currently considered an issue in states with net pen aquaculture (Washington State, Maine and Hawaii) but simulation of multiple farms in an area with persistent onshore currents on the northwest coast of the island of Hawaii indicates the possibility of measurable nitrogen flux to coral reefs in the nearshore waters (O'Brien *et al*., 2011). This may or may not cause changes to the reefs but is an issue in oligotrophic and tropical waters worldwide.

1.6.3 Shellfish Culture

Oysters, and primarily the Pacific oyster (*Crassostrea gigas*), are by far the dominant shellfish produced along the west coast of the United States, with Washington State production exceeding that in all other states and often leading the United States in farmed product. Clams, including the Manila clam (*Venerupis phillipinarum*), and the geoduck (*Panopea generosa*) are the second most valuable product with value of geoduck production from Washington State alone almost equaling that of other clams in all other coastal states due to its high market value. Mussels (*Mytilus edulis* and *Mytilus galloprovincialis*) are the third most valuable product. Efforts to expand the shellfish culture industry are currently underway.

Near-field effects

The majority of research on the environmental interactions of shellfish aquaculture on the west coast of the United States has focused on oyster or clam aquaculture which is conducted directly on bottom or near bottom on suspended racks or longlines. In the following, we divide the discussion between suspension culture and on-bottom culture and include rack and bag and longline culture of shellfish in the latter category.

Suspension culture

Research on the effects of suspended mussel culture has been conducted primarily on the Atlantic coast of the United States and Canada, with the exception of one research project in Puget Sound. The only other significant suspended shellfish culture operations on the U.S. west coast are for oysters which are hung from rafts attached to pilings in some estuaries (*e.g.*, Drakes Estero, California, and Yaquina Bay, Oregon).

Physical changes

The addition of cultured bivalves creates structure by adding not only the suspended bivalves themselves (in socks or on strings or lantern nets), but also the pilings, docks, or rafts from which they are suspended. These lead to the addition of habitat for organisms that are attracted to the structure and either settle and create their own structure (*e.g.*, fouling organisms) or use it for shelter and/or food. Further, the addition of structure leads to reduced flow and enhanced deposition of sediments, feces and other material like cultured shellfish themselves, dead organisms and shells to the bottom below the structure. Depending on the depth of the water column and/or height of the structure above the bottom, the culture system has the potential to shade the bottom which could impact submerged aquatic vegetation. Studies on mussel rafts in Puget Sound suggested that flow decreased markedly at the surface within the rafts, but varied substantially with existing current speed and tidal direction just downstream (Brooks, 2006). The reduced flow influenced phytoplankton density and mussel growth as well as deposition of sediment below the rafts. Some scouring, sandier sediments and loss of submerged aquatic vegetation was observed near the base of oyster racks in Drakes Estero, which occur over relatively shallow bottom (NRC, 2009). The magnitude and spatial extent of these effects are site specific and depend on shellfish stocking density and especially on pre-existing tidal currents and other physical conditions.

Chemical changes

The addition of bivalves to a system necessarily influences benthic pelagic coupling and the nutrient cycle in coastal systems. Bivalves consume phytoplankton and excrete wastes, some of which are deposited to the sediments below the culture racks. Water column nitrate and ammonium levels were shown to increase near the center of mussel racks in Puget Sound, but declined rapidly away from the rafts (Brooks, 2006). Feces and organic material deposited on the bottom increased the concentration of free sediment sulfides in the sediments below the racks, but these conditions declined exponentially away and down-current from the raft. Similar to direct physical effects noted above, these changes were also influenced by existing hydrography and bathymetry, with significant effects only observed at a site with slower tidal flow. No differences in sediment organic content were found beneath oyster racks *versus* areas outside of the oyster rack footprint in Drakes Estero, perhaps due to current flow or the significant contribution of eelgrass detritus to sediments in both locations (Harbin-Ireland, 2004).

Biological changes

Suspended bivalve culture can directly affect the composition of the plankton community *via* water filtration. Mussel rafts in Puget Sound significantly reduced the amount of seston within the water column. Mussels fed extensively on diatoms which significantly reduced their concentration within the raft area, but dinoflagellate concentrations were less affected (Pacific Shellfish Institute, 2002).

A diverse community of epibionts also develops on the rafts and suspended cultures that feeds and contributes to the processes already discussed and provides food for more mobile fish. The biomass of this community represented up to 20% of that of the mussels in Puget Sound (Brooks, 2005) and consisted primarily of other bivalves, polychaetes, arthropods, cnidarians, and nematodes. Some members of this fouling community may be introduced species like tunicates which not only have caused problems for the shellfish in some locations (Locke *et al*., 2009), but are also of concern to managers attempting to control their spread and keep them from altering native communities (*e.g.*, the invasive tunicate *Didemnum* is present on oyster racks in Drakes Estero; Harbin-Ireland, 2004).

Physical and chemical differences in the sediments below suspended aquaculture can lead to differences in the benthic community. The abundance of one polychaete (*Paraprionospio*) and a clam (*Macoma*) were significantly reduced under a mussel culture site in Puget Sound, but no differences were observed in overall community diversity or richness. These differences would also be tied to the quantity of shellfish being raised and to the local conditions. Further, any deposition of fouling organisms or debris from the culture operation would be expected to enhance structure and change the bottom community. This has been documented in Canada (D'Amours *et al*., 2008; McKindsey *et al*., 2011), but not in the United States.

On-bottom culture

The majority of research on the effects of shellfish aquaculture conducted along the west coast of the United States has focused on intertidal culture of oysters and clams. Oysters are grown utilizing a variety of methods including on-bottom culture, floating bags, rack and bag systems, longlines and trays. In on-bottom culture, cultch with attached oysters is placed directly on the intertidal (generally < +0.6 m MLLW) and shallow subtidal sediment surface where it is left until the oysters reach market size, usually in 1 to 3 years, depending on location and temperature. Oysters are harvested from on-bottom culture by hand (picked into baskets and tubs) or with mechanical or suction dredges. In longline culture, seeded cultch is strung on lines or ropes that are suspended from stakes or rails and harvest is usually by hand. Cultchless oysters are often grown in high-density polyethylene (HDPE) or poly-propylene mesh bags placed on the bottom, suspended off the bottom on racks, or placed in floating bags attached to longlines (Conte *et al*., 1994).

Farmed Manila clams are planted in a grow-out area or placed in mesh bags for grow-out (Toba *et al*., 1992). Several techniques are employed to enhance the ground for clam production. Growers sometimes add gravel or oyster shell (Toba *et al*., 1992; Thompson, 1995) which provides a substrate for the attachment of naturally settled clams and potentially makes feeding more difficult for some predators. Plastic or nylon netting of varying mesh is also often placed over clam beds to reduce predation. Manila clam aquaculture tends to occur higher (0.6–1.2 m MLLW) in the intertidal zone than does oyster culture. Harvest of planted tideflats is generally with a hand operated rake to collect clams, which grow close to the surface, but some mechanized harvest methods have also been recently developed.

Aquaculture techniques for the much larger geoduck clam (*Panopea generosa*) have been applied primarily to intertidal flats, and crop cycles are currently about 5–6 years since growth is fast during initial years and then slows. Geoduck culture techniques continue to evolve with survival in the hatchery and grow-out phases being highly variable. To date, growers have mostly planted small hatchery produced clams (1 cm length) in tubes made by cutting 10–15 cm diameter PVC pipe into 30 cm long sections and partially embedding them in the sediment to protect them from predation. Several geoducks are added to each tube, and mesh is placed over the top to exclude crabs and predatory snails (Beattie, 1992). This mesh may cover tubes individually or extend over a group of many tubes, anchored only at the edges. The tubes are removed after 1–2 years and the geoducks continue to grow for several more years before reaching market size (15 cm shell length, approximately 1 kg whole weight). Harvest methods involve loosening the sediment around each geoduck with low pressure but high volume seawater from a small pump and forced through narrow tubes into the sediment. Geoducks then come to the surface and are harvested by hand.

Physical changes

As with suspended culture, the addition of oysters creates structure by adding both the animals themselves and structures like racks and bags or PVC poles and longlines. This changes the ecology of the area which, in most cases, would have been dominated by soft substrate and adds solid three-dimensional hard structure that attracts other organisms. Further, the addition of structure and organisms can lead to reduced flow and enhanced deposition of sediments and bivalve fecal material. The magnitude and spatial extent of these effects are site specific and depend on shellfish stocking density and especially on pre-existing tidal currents and other physical conditions. Experimental manipulations of oysters have demonstrated that additions of oysters either on closely spaced longlines or at relatively high density on-bottom can lead to reduced grain size and higher nutrient content, but this is not always the case at commercial planting density (see Dumbauld *et al*., 2009 for review). In some cases the racks and short poles on which the shellfish are grown can also lead to sediment erosion and larger grain size near the base of the structures (Everett *et al*., 1995; Rumrill and Poulton, 2004).

As noted above, infaunal clams are often grown under netting or, in the case of geoducks, in tubes and these structures have also been shown to influence sediment properties by altering flow. Though little consistent change in grain size has been noted for the addition of predator netting alone, the clams have been shown to alter the organic carbon content and, more importantly, clam growers also directly alter the physical character of the sediments by adding gravel and crushed shell (Thompson, 1995).

Chemical changes

The addition of bivalves to a system influences benthic pelagic coupling and nutrient cycling in coastal systems. Bivalves consume phytoplankton and excrete wastes, some of which are deposited to the sediments, but these effects are not well explored for bottom culture of shellfish along the west coast of the United States. Richardson *et al*. (2007) found no differences in sediment properties between areas with bottom oyster culture and those outside the beds. Experimental additions of both oysters and geoducks have demonstrated enhanced porewater ammonium, and oysters, but not clams, affected sediment grain size and organic content compared to controls (Ruesink and Rowell, 2012; Wagner *et al*., in prep).

Biological changes

Shellfish aquaculture provides structured benthic habitat, but also reduces or changes this structure in existing seagrass habitats. This is relevant because seagrass is declining in many locations worldwide (Orth *et al*., 2006; Hughes *et al*., 2009; Waycott *et al*., 2009) and along with other vegetated habitats like salt marshes, usually serves as a benchmark for habitat comparisons. Seagrass is protected in the United States due to its presumed value as essential fish habitat (under the *Magnuson Stevens Act*) or as habitat for other protected species (under the *Endangered Species Act*). The addition of bivalve shellfish like oysters might be expected to simply replace seagrass habitat *via* space competition, but research on the U.S. west coast suggests that the tradeoff is not 1:1 and a threshold exists below which shoot density of eelgrass (*Zostera marina*) declined markedly after 1 year (1.3% oyster cover), 2 years (12.4%), and 3 years (21.9%; Wagner *et al*., in prep.). Though nutrients in sediments and porewater were enhanced by the presence of oysters, eelgrass shoot size was reduced, but eelgrass growth rate was not, apparently because nutrients were not limiting in the estuary studied. This response may clearly differ depending on existing conditions. The influence of longline culture has also been examined with eelgrass being limited by light and potential shading as well as by dessication and stranding over the lines (Rumrill and Poulton, 2004).

Shellfish harvest practices also directly influence eelgrass, with mechanical dredges directly removing plants, and this practice causes more eelgrass disturbance than longline culture or on-bottom harvest by hand picking (Tallis *et al.*, 2009). In all cases, total production of eelgrass was reduced in areas of oyster mariculture, but eelgrass recovery took place after 2 to 3 years. Contrary to expectation, eelgrass seedling survival and growth was greater in dredge-harvested areas where more eelgrass had been removed and remaining shoots caused less shading (Wisehart *et al.*, 2007). Ecosystem- or estuary-scale studies are necessary to define the overall impact but initial estimates from a portion of one estuary (Willapa Bay, Washington), where up to 20% of oysters harvested in the United States are produced, clearly depicted reductions of eelgrass cover on individual beds, suggesting that, on average, there was little difference in overall eelgrass cover inside and outside of oyster aquaculture areas (Dumbauld *et al.*, 2009). Seagrass is apparently expanding in this estuary, however, so existing conditions should always be considered.

Most U.S. west coast clam aquaculture does not co-occur with native seagrass, but recent work on intertidal geoduck clam aquaculture suggests that harvest disturbance to eelgrass is similar to that observed with oysters, with initial shoot density dropping by more than 70% and small gaps created in eelgrass beds which take over a year to recover. Geoducks are initially grown in plastic tubes and when planted in eelgrass (which is rarely the case), a reduction in eelgrass density and shoot length was observed.

On-bottom shellfish aquaculture directly influences benthic infauna and epibenthic meiofauna *via* changes to the nutrient chemistry and grain size of the sediments, creation of hard substrate for settlement and/or protection of smaller organisms from predators, and *via* harvest practices which remove the shellfish and can also change the substrate. The extent of these changes varies with species being cultured, culture practice and particularly with existing conditions. Several studies have demonstrated that the benthic infaunal community in U.S. west coast estuaries is more diverse in oyster aquaculture than in open unstructured habitats and either comparable or slightly less diverse than that found in other structured habitats like eelgrass (Hosack *et al.*, 2006; Ferraro and Cole, 2011). Though clams do not directly structure the surface of the sediment, the presence of clams, culture practices like gravel and shell addition, the addition of predator netting, and harvest practices have also been shown to influence the benthic community (Thompson, 1995). Fewer studies of epibenthic meiofauna have been conducted but they too, suggest taxa-specific results and a diverse community associated with structure like bivalve shells compared to open unstructured mudflat.

Aquaculture has been a vector for the introduction of non-native species, including the cultured organisms themselves into estuarine systems (Carlton, 1992; Ruesink *et al*., 2006). Potential negative environmental and economic consequences of such introductions resulted in the implementation of import and transport regulations at state, federal and international levels (such as the ICES codes of practice, ICES, 2005) that, along with best management practices in the United States, have greatly reduced these threats. Although no new introductions of non-native bivalves have occurred recently, evidence suggests that previous introductions continue to have effects, *e.g.*, Pacific oysters have naturalized and spread in some locations with attendant effects on native oysters and community (Trimble *et al.*, 2009; Padilla, 2010), accidentally introduced oyster pests like oyster drills continue to impact both commercial aquaculture and native communities (Buhle and Ruesink, 2009), and fouling organisms expand their distribution on hard substrates provided by oysters and structures.

Shellfish disease agents have also been transferred *via* movement of infected stocks and this has occurred on the west coast of the United States (Friedman *et al*., 1989; Friedman, 1996; Burge *et al*., 2007). Like other introduced species transfers, occurrences have been reduced with regulations and voluntary participation in the High Health Program, but there is potential for additional problems. Other issues have surfaced, such as escape or natural spawning behavior of the shellfish being raised such that the genetic pool of wild stock is influenced by the captive animals (Camara and Vadopalas, 2009), but little research has been directed at these issues.

Although more mobile fish and invertebrates have also been shown to associate with structured habitats like eelgrass and oyster aquaculture, the majority were less likely to do so than sedentary fauna in U.S. west coast estuaries (reviewed in Dumbauld *et al.*, 2009). Nonetheless, on-bottom oyster aquaculture has been clearly associated with enhanced abundance of juvenile 0+ Dungeness crab as well as slightly larger rock crab (Dumbauld *et al*., 2000; Feldman *et* *al*., 2000; Holsman *et al*., 2006). Studies of other economically important species that utilize U.S. west coast estuaries as nursery areas are ongoing.

Birds and marine mammals could also be affected by shellfish aquaculture activities with direct human disturbance of behavior and disturbance of food sources being the primary issues. Virtually no studies document direct or indirect effects of disturbance on behavior (but see NRC (2009) for a review of potential impacts to seals in Drakes Estero). Only a few studies have been conducted in U.S. estuaries, and they suggest that foraging behavior of some shorebirds can be negatively affected (deep probers) while other birds adapt to and feed in aquaculture plots (surface oriented feeders; Kelly *et al*., 1996; Connolly and Colwell, 2005). Waterfowl like black brant could also be affected if their primary food source (eelgrass) was in short supply and aquaculture was being conducted in that habitat, but no studies have examined whether food is a limiting factor at the estuarine ecosystem scale for birds or most other fish and invertebrates.

Far-field effects

Suspension culture

Far-field effects of suspension culture depend on the specifics of the site (bathymetry, hydrography) and shellfish culture operation (raft size, density of organisms, placement of lines, *etc.*). Some work had been done for mussel raft culture in South Puget Sound, which suggests that no effects on water column parameters could be observed beyond about 70 m away from mussel rafts. No research on the landscape-scale effects of suspended culture operations has been completed on the U.S. west coast. However, most of the physical, chemical and especially biological effects for mussels and oysters discussed above have been found to decrease rapidly just outside the site and disappear within several hundred meters.

On-bottom culture

Far-field effects of on-bottom culture have been little explored, but few direct effects have been observed beyond the boundary of the shellfish aquaculture operations themselves. Understanding the role of shellfish aquaculture at the landscape scale where aquaculture is intermixed with other estuarine habitats and how this influences water properties and more mobile fish and invertebrates, however, is an important avenue for future research. Some progress has been made in initial investigations at intermediate scales in Willapa Bay, Washington, where aquaculture is conducted on, and influences about, 20% of the intertidal estuarine area (Dumbauld *et al*., 2011). Effects of intertidal oyster culture on submerged aquatic vegetation can be assessed using infrared aerial photography, and a preliminary analysis for a small section of the estuary suggested that as much eelgrass occurred inside aquaculture as that in a buffer zone just outside and adjacent to it (Dumbauld *et al*., 2009). This represents a single snapshot and a more comprehensive approach is currently being used to quantify changes occurring over a longer temporal scale (the lifetime of a shellfish crop). The ecosystem services provided by all estuarine habitats, including shellfish aquaculture, could then be evaluated at this larger scale and weighed against other anthropogenic changes made to these systems.

1.6.4 Integrated Multi-Trophic Aquaculture

Integrated multi-trophic marine aquaculture (IMTA) appears to hold promise as a means to capture some particulate and dissolved wastes from fish aquaculture and obtain multiple products, but is only now being experimented with and has not yet been practiced at a commercial scale along the U.S. west coast (Rensel *et al*., 2011). Results of an initial study showed that Pacific oysters but not mussels, suspended at depth below Atlantic salmon net pens, grew faster than those grown at the same depth outside of the farm footprint, but site was an important factor as well. The benefit appeared to be due to consumption of fish feces by the shellfish based on stable isotope mixing analyses and although oysters are not likely to replace fish as the cash crop on these farms, the experiments highlighted the potential for further investigation and scaled up trials (Rensel *et al*., 2011). IMTA appears to be a useful tool to limit adverse effects of fish aquaculture in net pens, particularly in areas less than optimal for large-scale farms such as restricted bays where a large percentage of the nitrogen flux is due to aquaculture.

1.6.5 Conclusions and Recommendations

Marine shellfish aquaculture has been a very important human endeavor in coastal waters along the west coast of the United States for over a century. Marine fish culture is more recent, but Pacific salmon hatchery operations to supplement wild fish runs have been in operation for about the same length of time. Research conducted to date and outlined above suggests that while there are recognized near-field impacts of current culture aquaculture at local spatial scales and over short time periods, the current activities appear to be sustainable. Aquaculture is expanding dramatically on a global scale, however, and there is a recognized need and recent policy development that supports continued development of sustainable marine aquaculture in the United States (NOAA, 2007, 2011). While there are numerous regulatory and social management hurdles to overcome if aquaculture is to be expanded in estuarine and nearshore waters where it already occurs, continued research, particularly on the far-field effects of culture operations and cumulative impacts (both positive and negative) at the ecosystem scale, is necessary. Further, development of techniques like integrated multi-trophic aquaculture, best management practices to minimize negative impacts, and research on the potential for offshore aquaculture will also influence its success in the United States.

1.6.6 References

Amos K.H. and Appleby A. 1999. Atlantic salmon in Washington State: A fish managment perspective. Washington State Department of Fish and Wildlife Report, Olympia, WA, 13 pp.

Anderson, D.M., Burkholder, J.M., Cochlan, W.P., Glibert, P.M., Gobler, C.J., Heil, C.A., Kudela, R.M., Parsons, M.L., Rensel, J.E.J., Townsend, D.W., Trainer, V.L. and Vargo, G.A. 2008. Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States. *Harmful Algae* **8**: 39–53.

Beattie, J.H. 1992. Geoduck enhancement in Washington State. *Bull. Aquaculture Assoc. Can.* **92**: 18–24.

Brooks, K.M. 2005. The epibenthic community observed in association with the intensive raft culture of *Mytilus galloprovincialis* in Totten Inlet, Washington. Unpublished technical report. Aquatic Environmental Sciences, Port Townsend, WA, 18 pp.

Brooks, K.M. 2006. Benthic response at the Deepwater Point mussel farm in Totten Inlet, Puget Sound, Washington State, U.S.A. Unpublished technical report. Aquatic Environmental Sciences, Port Townsend, WA, 45 pp.

Brooks, K.M. 2009. Considerations in developing an integrated pest management programme for control of sea lice on farmed salmon in Pacific Canada. *J. Fish Dis*. **32**: 59–73.

Brooks, K.M. and Jones, S.R.M. 2008. Perspectives on pink salmon and sea lice: Scientific evidence fails to support the extinction hypothesis. *Rev. Fish. Sci*. **16**: 403–412.

Brooks, K.M. and Mahnken, C.V.W. 2003a. Interactions of Atlantic salmon in the Pacific northwest environment II. Organic wastes. *Fish. Res*. **62**: 255–293.

Brooks, K.M. and Mahnken, C.V.W. 2003b. Interactions of Atlantic salmon in the Pacific Northwest environment III. Accumulation of zinc and copper. *Fish. Res.* **62**: 295–305.

Brooks, K.M., Stierns, A.R. and Backman, C. 2004. Seven year remediation study at the Carrie Bay Atlantic salmon (*Salmo salar*) farm in the Broughton Archipelago, British Columbia, Canada. *Aquaculture* **239**: 81–123.

Brooks, K.M., Stierns, A.R., Mahnken, C.V.W. and Blackburn, D.B. 2003. Chemical and biological remediations of the benthos near Atlantic salmon farms. *Aquaculture* **219**: 355–377.

Buhle, E.R. and Ruesink, J.L. 2009. Impacts of invasive oyster drills on Olympia oyster (*Ostrea lurida* Carpenter) recovery in Willapa Bay, Washington, USA. *J. Shellfish Res*. **28**: 87–96.

Burge, C.A., Judah, L.R., Conquest, L.L., Griffin, F.J., Cheney, D.P., Suhrbier, A., Vadopalas, B., Olin, P.G., Renault, T. and Friedman, C.S. 2007. Summer seed mortality of the Pacific oyster, *Crassostrea gigas* Thunberg grown in Tomales Bay, California, USA: The influence of oyster stock, planting time, pathogens, and environmental stressors. *J. Shellfish Res*. **26**: 163–172.

Camara, M.D. and Vadopalas, B. 2009. Genetic aspects of restoring Olympia oysters and other native bivalves: Balancing the need for action, good intentions, and the risks of making things worse. *J. Shellfish Res.* **28**: 121–145.

Carlton, J.T. 1992. Introduced marine and estuarine mollusks of North America: an end-of-the-20th-century-perspective. *J. Shellfish Res*. **11**: 489–505.

Chamberlain, J. and Stucchi, D. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. *Aquaculture* **272**: 296–311.

Cheney, D., Langan, R., Heasman, K., Friedman, B. and Davis, J. 2010. Shellfish culture in the open ocean: lessons learned for offshore expansion. *Mar. Tech. Soc. J*. **44**: 55–67.

Connolly, L.M. and Colwell, M.A. 2005. Comparative use of longline oysterbeds and adjacent tidal flats by waterbirds. *Bird Cons. Int*. **15**: 237–255.

Conte, F.S., Harbell, S.C. and RaLonde, R.L. 1994. Oyster Culture: Fundamentals and technology of the West Coast industry. Report to the Western Regional Aquaculture Center Seattle, WA, 150 pp.

Cromey C.J., Nickell, T.D. and Black, K.D. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. *Aquaculture* **214**: 211–239.

D'Amours, O., Archambault, P., McKindsey, C.W. and Johnson, L.E. 2008. Local enhancement of epibenthic macrofauna by aquaculture activities. *Mar. Ecol. Prog. Ser*. **371**: 73–84.

Dumbauld, B., Visser, E., Armstrong, D.A., Cole-Warner, L., Feldman, K. and Kauffman, B. 2000. Use of oyster shell to create habitat for juvenile Dungeness crab in Washington coastal estuaries: Status and prospects. *J. Shellfish Res*. **19**: 379–386.

Dumbauld, B.R., Ruesink, J.L. and Rumrill, S.S. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam culture in West Coast (USA) estuaries. *Aquaculture* **290**: 196–223.

Dumbauld, B.R., Ruesink, J.L., Trimble, A.C. and Kauffman, B.E. 2011. The Willapa Bay oyster reserves in Washington State: Fishery collapse, creating a sustainable replacement, and the potential for habitat conservation and restoration. *J. Shellfish Res*. **30**: 71–83.

Everett, R.A., Ruiz, G.M. and Carlton, J.T. 1995. Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. *Mar. Ecol. Prog. Ser*. **125**: 205–217.

Feldman, K.L., Armstrong, D.A., Dumbauld, B.R., DeWitt, T.H. and Doty, D.C. 2000. Oysters, crabs, and burrowing shrimp: Review of an environmental conflict over aquatic resources and pesticide use in Washington State's (USA) coastal estuaries. *Estuaries* **23**: 141–176.

Ferraro, S.P. and Cole, F.A. 2011. Ecological periodic tables for benthic macrofaunal usage of estuarine habitats in the US Pacific Northwest. *Estuar. Coast. Shelf Sci*. **94**: 36–47.

Friedman, C.S. 1996. Haplosporidian infections of the Pacific oyster, *Crassostrea gigas* (Thunberg), in California and Japan. *J. Shellfish Res*. **15**: 597–600.

Friedman, C.S., McDowell, T., Groff, J.M., Hollibaugh, J.T., Manzer, D. and Hedrick, R.P. 1989. Presence of *Bonamia ostreae* among populations of the European flat oyster, *Ostrea edulis* Linne, in California, USA. *J. Shellfish Res*. **8**: 133–137.

Harbin-Ireland, A.C. 2004. Effects of oyster mariculture on the benthic invertebrate community in Drakes Estero, Pt. Reyes Peninsula, California. M.S. thesis, University of California, Davis, CA.

Holsman, K.K., McDonald, P.S. and Armstrong, D.A. 2006. Intertidal migration and habitat use by subadult Dungeness crab *Cancer magister* in a NE Pacific estuary. *Mar. Ecol. Prog. Ser*. **308**: 183–195.

Hosack, G.R., Dumbauld, B.R., Ruesink, J.L. and Armstrong, D.A. 2006. Habitat associations of estuarine species: Comparisons of intertidal mudflat, seagrass (*Zostera marina*), and oyster (*Crassostrea gigas*) habitats. *Estuaries Coasts* **29**: 1150–1160.

Hughes, A.R., Williams, S.L., Duarte, C.M., Heck, K.L. and Waycott, M. 2009. Associations of concern: declining seagrasses and threatened dependent species. *Front. Ecol. Environ*. **7**: 242–246.

ICES (International Council for the Exploration of the Sea). 2005. ICES Code of Practice on the Introductions and Transfers of Marine Organisms, 30 pp.

Kelly, J.P., Evens, J.G., Stallcup, R.W. and Wimpfheimer, D. 1996. Effects of aquaculture on habitat use by wintering shorebirds in Tomales Bay, California. *Calif. Fish Game* **82**: 160–174.

Kiefer, D.A., Rensel, J.E., O'Brien, F.J., Fredriksson, D.W. and Irish, J. 2011. An ecosystem design for marine aquaculture site selection and operation. NOAA Marine Aquaculture Initiative Program Final Report. System Science Applications, Irvine, CA, 182 pp.

Krkosek, M., Morton A., Volpe J.P. and Lewis M.A. 2009. Sea lice and salmon population dynamics: effects of exposure time for migratory fish. *Proc. Roy. Soc. Lond. B* **276**: 2819–2828.

Locke, A., Doe, K.G., Fairchild, W., Jackman, P.M. and Reese, E.J. 2009. Preliminary evaluation of effects of invasive tunicate management with acetic acid and calcium hydroxide on non-target marine organisms in Prince Edward Island, Canada. *Aquat. Invasions* **4**: 221–236.

Mackas, D.L. and Harrison, P.J. 1997. Nitrogenous nutrient sources and sinks in the Juan de Fuca Strait Strait of Georgia Puget Sound estuarine system: Assessing the potential for eutrophication. *Estuar. Coast. Shelf Sci*. **44**: 1–21.

Marty, G.D., Saksida, S.M. and Quinn, II, T.J. 2010. Relationship of farm salmon, sea lice, and wild salmon populations. *Proc. Natl. Acad. Sci. U.S.A.* **107**: 22,599–22,604.

McKindsey, C.W., Archambault, P., Callier, M.D. and Olivier, F. 2011. Influence of suspended and off-bottom mussel culture on the sea bottom and benthic habitats: a review. *Can. J. Zool.* **89**: 622–646.

Morton, A., Routledge, R., McConnell, A. and Krkosek, M. 2011. Sea lice dispersion and salmon survival in relation to salmon farm activity in the Broughton Archipelago. *ICES J. Mar. Sci.* **68**: 144–156.

Nash, C.E. 2003. Interactions of Atlantic salmon in the Pacific Northwest. VI. A synopsis of the risk and uncertainty. *Fish. Res*. **62**: 339–347.

Nash, C.E., Burbridge, P.R. and Volkman, J.K. 2005. Guidelines for ecological risk assessment of marine fish aquaculture. NOAA Technical Memorandum. U.S. Dept. of Commerce, NOAA NMFS-NWFSC-71, 90 pp.

NOAA (National Oceanic and Atmospheric Administration). 2007. NOAA 10 year plan for marine aquaculture. National Oceanic and Atmospheric Administration, Silver Springs, MD.

NOAA. 2011. Marine aquaculture policy. National Oceanic and Atmospheric Administration, Silver Springs, MD.

NRC (National Research Council). 2009. Shellfish Mariculture in Drakes Estero, Point Reyes National Seashore, California. National Academies Press, Washington, DC, 138 pp.

NRC. 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. National Academies Press, Washington, DC, 179 pp.

Normandeau and Associates and Battelle. 2003. Maine aquaculture review. Maine Department of Marine Resources, West Boothbay Harbor, ME, 54 pp.

O'Brien, F., Kiefer, D. and Rensel, J. 2011. Aquamodel: Software for sustainable development of open ocean fish farms. Systems Science Applications, Irvine, CA.

Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M. and Williams, S.L. 2006. A global crisis for seagrass ecosystems. *Bioscience* **56**: 987–996.

Pacific Shellfish Institute. 2002. Ecological characteristics and carrying capacity of suspended shellfish culture Systems. Available at http://www.lib.noaa.gov/retiredsites/docaqua/nmaimages2001/mussel2001.htm

Padilla, D.K. 2010. Context-dependent impacts of a non-native ecosystem engineer, the Pacific oyster *Crassostrea gigas*. *Integr. Comp. Biol*. **50**: 213–225.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Annu. Rev. Oceanogr. Mar. Biol.* **16**: 229–311.

Rensel Associates and PTI Environmental Services. 2001. Nutrients and phytoplankton in Puget Sound. Report to the U.S. Environmental Protection Agency, Seattle, WA. EPA 910/9-91-002, 131pp.

Rensel, J.E. 1989. Phytoplankton and nutrient studies near salmon net-pens at Squaxin Island, Washington. Technical appendices of the State of Washington's Programmatic Environmental Impact Statement: Fish Culture in Floating Net-pens. Report to Washington Department of Fisheries, Olympia, WA, 312 pp.

Rensel, J.E. 2001. Salmon net pens in Puget Sound: Rules, performance criteria and monitoring. An overview of net pen permitting and monitoring in Washington State. *Global Aqua. Advoc*. **4**: 66–69.

Rensel, J.E., Kiefer, D.A. and O'Brien, F.J. 2006. Modeling water column and benthic effects of fish mariculture of cobia (*Rachycentron canadum*) in Puerto Rico: Cobia AquaModel. Prepared for Ocean Harvest Aquaculture Inc., Puerto Rico, and the National Oceannic and Atmospheric Administration. Systems Science Applications, Inc., Los Angeles, CA, 60 pp.

Rensel, J.E., Kiefer, D.A., Forster, J.R.M., Woodruff, D.L. and Evans, N.R. 2007. Offshore finfish mariculture in the Strait of Juan de Fuca *Bull. Fish. Res. Agency* **19**: 113–129.

Rensel, J., Bright, K., King, G. and Siegrist, Z. 2011. Integrated fish-shellfish mariculture in Puget Sound. Rensel Associates Aquatic Sciences, Arlington, WA, 82 pp.

Richardson, N.F., Ruesink, J.L., Naeem, S., Hacker, S.D., Tallis, H.M., Dumbauld, B.R. and Wisehart, L.M. 2007. Bacterial abundance and aerobic microbial activity across natural and oyster aquaculture habitats during summer conditions in a Northern Pacific estuary. *Hydrobiologia* **596**: 269–278.

Ruesink, J.L. and Rowell, K. 2012. Seasonal effects of clams (*Panopea generosa*) on eelgrass (*Zostera marina*) density but not recovery dynamics at an intertidal site. *Aquat. Conserv. Mar. Fresh. Ecosys.* **22**: 712–720.

Ruesink, J.L., Feist, B.E., Harvey, C.J., Hong, J.S., Trimble, A.C. and Wisehart, L.M. 2006. Changes in productivity associated with four introduced species: ecosystem transformation of a "pristine" estuary. *Mar. Ecol. Prog. Ser.* **311**: 203–215.

Rumrill, S.S. and Poulton, V.K. 2004. Ecological role and potential impacts of molluscan shellfish culture in the estuarine environment of Humboldt Bay, Ca. Final Annual Report to the Western Regional Aquaculture Center, Book Annual Report 2004. Oregon Department of State Lands.

Saksida, S.M., Greba, L., Morrison, D. and Revie, C.W. 2011. Sea lice on wild juvenile Pacific salmon and farmed Atlantic salmon in the northernmost salmon farming region of British Columbia. *Aquaculture* **320**: 193–198.

Tallis, H.M., Ruesink, J.L., Dumbauld, B.R., Hacker, S.D. and Wisehart, L.M. 2009. Oysters and aquaculture practices affect eelgrass density and productivity in a Pacific Northwest estuary. *J. Shellfish Res*. **28**: 251–261.

Thompson, D.S. 1995. Substrate additive studies for the development of hardshell clam habitat in Washington State: An analysis of effects on recruitment, growth and survival of the Manila clam, *Tapes philippinarum*, and on the species diversity and abundance of existing benthic organisms. *Estuaries* **18**: 91–107.

Toba, D.R., Chew, K.K., Thompson, D.S., Anderson, G.J. and Miller, M.B. 1992. Guide to Manila Clam Culture., Washington Sea Grant, University of Washington, Seattle, WA, 80 pp.

Trimble, A.C., Ruesink, J.L. and Dumbauld, B.R. 2009. Factors preventing the recovery of a historically overexploited shellfish species, *Ostrea lurida* Carpenter 1864. *J. Shellfish Res*. **28**: 97–106.

Wagner, E.L., Ruesink, J.L., Dumbauld, B.R., Hacker, S.D. and Wisehart, L.M. (in prep.) Density-dependent effects of oysters (*Crassostrea gigas*) on intertidal eelgrass (*Zostera marina*) in small scale experiments.

Waknitz, F.W., Iwamoto, R.N. and Strom, M.S. 2003. Interactions of Atlantic salmon in the Pacific northwest IV. Impacts on the local ecosystems. *Fish. Res*. **62**: 307–328.

Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Heck, Jr., K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, J.W., Short, F.T. and Williams, S.L. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Acad. Natl. Sci. Philadelphia* **106**: 12,377–12,381.

WDF (Washington Department of Fisheries). 1990. Fish culture in floating net pens – a final programmatic environmental impact statement. Olympia, WA, 199 pp.

Weston, D.P. 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. *Mar. Ecol. Prog. Ser.* **61**: 233–244.

Wisehart, L.M., Ruesink, J.L., Hacker, S.D. and Dumbauld, B.R. 2007. Importance of eelgrass early life history stages in response to oyster aquacuture disturbance. *Mar. Ecol. Prog. Ser.* **344**: 71–80.

2 Marine Aquaculture Legislative Frameworks and Environmental Interactions Research in PICES Member Countries

2.1 Overview

Throughout the different PICES member countries, the legislative framework that governs marine aquaculture operations also influences the scope and focus of environmental interactions research. Risk assessment approaches may be undertaken as part of the formal legislative process, or may not be specifically defined through either the legislative or regulatory mechanisms. This section focuses on outlining the legislative frameworks specific to each member country, how risk assessment is integrated into this process, and the supporting research that is being undertaken to address questions related the environmental interactions with aquaculture.

2.2 Canada

In Canada, aquaculture is a relatively new industry that has expanded rapidly over the last two decades. The Government of Canada recognizes the significant benefits to society associated with aquaculture and has made sustainable aquaculture development a key priority.

2.2.1 Legislative Framework for Risk Assessment of Aquaculture

Within the federal government there are 17 departments and agencies that have direct influence on aquaculture development, ranging from research and technology transfer, training and development, environmental sustainability, regulation, product safety and inspection, foreign market and trade services, and access to financing and communications. Fisheries and Oceans Canada (DFO) is the lead federal department for the sustainable management of fisheries and aquaculture.

With the exception of British Columbia and Prince Edward Island, provincial governments are generally responsible for issuing licenses and permits and regulating farm activities, including escapes, waste management, and those aquatic animal health aspects that are of provincial concern.

DFO is responsible for administering, monitoring and enforcing compliance with regulations relating to conservation and protection, environment and habitat protection under the *Fisheries Act* and aquatic animal health under the Fish Health Protection Regulations. As of December 18, 2010, DFO assumed a greater role in the management of aquaculture activities in the province of British Columbia (see Figure 2.2.1), through the new Pacific Aquaculture Regulations. Under the *Fisheries Act*, the Pacific Aquaculture Regulations, and the Fishery (General) Regulations, DFO now governs certain activities regarding the cultivation of fish in British Columbia. Specifically, finfish, shellfish and freshwater aquaculture operations within the province will require a federal aquaculture license issued under the *Fisheries Act*, a federal *Navigable Waters Protection Act* permit and a provincial lease. British Columbia remains a key player, issuing tenures where operations take place in the marine or freshwater environment, licensing marine plant cultivation, and managing business aspects of aquaculture such as workplace health and safety.

On December 22, 2010, the Health of Animals Regulations were amended to specifically include aquatic animals. The *Health of Animals Act* and Health of Animals Regulations regulate international trade in live animals, animal products and by-products, animal feeds, veterinary biologics and biotechnology products. In addition, they provide for the approval and registration of private quarantine premises and establishments involved in the importation of animals, animal products and veterinary biologics. They also set standards of construction, operation and maintenance for these facilities and establishments. The Canadian Food Inspection Agency (CFIA), the agency responsible for the *Health of Animals Act*, also amended the Reportable Diseases Regulations in January, 2011, to include 20 diseases that pose serious risks to aquatic animal health, international trade, and the economy. The CFIA is responsible for the administration and enforcement this *Act*. These changes will be phased in over the next several years. Eventually DFO expects to rescind the Fish Health Protection Regulations to avoid regulatory duplication and overlap with the Health of Animals Regulations.

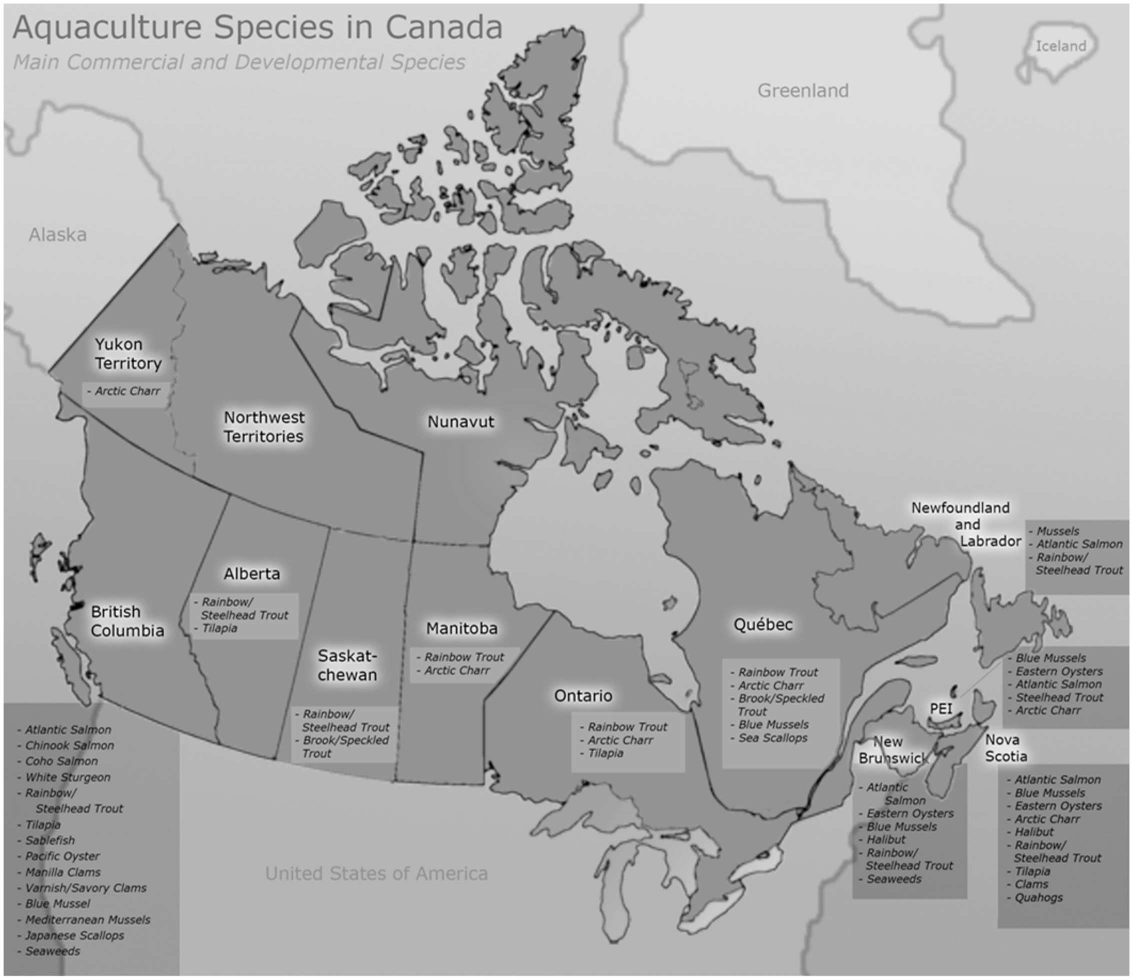


Fig. 2.2.1 Aquaculture species used in production or in development in Canada.

Under the *Fisheries Act*, Section 43 provides enabling authority for the Governor in Council to make regulations for the conservation and protection of fisheries resources, including the taking or carrying of fish or any part thereof from one province to any other province. The authority to issue licenses permitting the release of live fish has been delegated to provincial ministers in only some provinces; the federal Minister of Fisheries and Oceans retains this power in the other provinces and the territories. The National Code on Introductions and Transfers (see http://www.dfo-mpo.gc.ca/science/enviro/ais-eae/code-eng.htm) establishes the principles and standards for the intentional introduction and/or transfer of aquatic organisms in order to protect these resources. The Introductions and Transfers Committees are responsible for assessing proposals to move aquatic organisms from one water body to another. The Code also provides all jurisdictions with a consistent process (the Risk Assessment procedure) for assessing the potential impacts of intentional introductions and transfers of aquatic organisms.

In Canadian licensing of aquaculture, and in the review of aquaculture operations, there are risk analysis protocols for the protection of navigable waters and habitat alteration, for disease control, for protection against disruption or destruction, for introduction and transfer of aquatic organisms, and for hazardous substances. For the purposes of risk analysis and assessment, the Government of Canada has adopted a definition of risk that aligns with the World Trade Organization’s definition. Specifically, risk is defined as “the product of the severity of the predicted change and the probability that prediction is correct”. Further, severity is defined as “the combination of the intensity of change, the geographic extent of change, and the duration of the change (including reversibility), and any time lag in the expression of the change”.

For construction projects on or near water and for aquatic activities (*e.g.*, fisheries or aquaculture operations), aquatic environmental risks must be analyzed in a sustainable ecosystem context. Various tools are being developed to support this analysis, including aquaculture-specific pathways of effects diagrams that have been recently validated through a scientific peer-review process (see the summarized science advice on the aquaculture pathways of effects diagrams at http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2009/2009_071_e.pdf).

For aquaculture activities, seven pathways of effects diagrams were developed for seven different stressor categories:

1. physical alteration of habitat structure,
2. alteration in light,
3. noise,
4. release of chemicals and litter,
5. release/removal of nutrients, non-cultured organisms, and other organic material,
6. release or removal of fish,
7. release of pathogens.

These seven pathways provide a pictorial overview of aquaculture activity stressors (Figure 2.2.2; for example, releasing cultured organisms into the environment (*i.e.*, escaped cultured fish) through equipment failure or accident and the potential effects that this activity may have on the receiving environment). The state of scientific knowledge to support or refute each stressor–effect linkage has been analyzed, and knowledge gaps identified. These diagrams and the scientific review of the evidence to support them have been used to develop the scientific underpinning of aquaculture policies under the new Pacific Aquaculture Regulations, and were designed to foster a consistent environmental approach to the management of aquaculture in Canada.

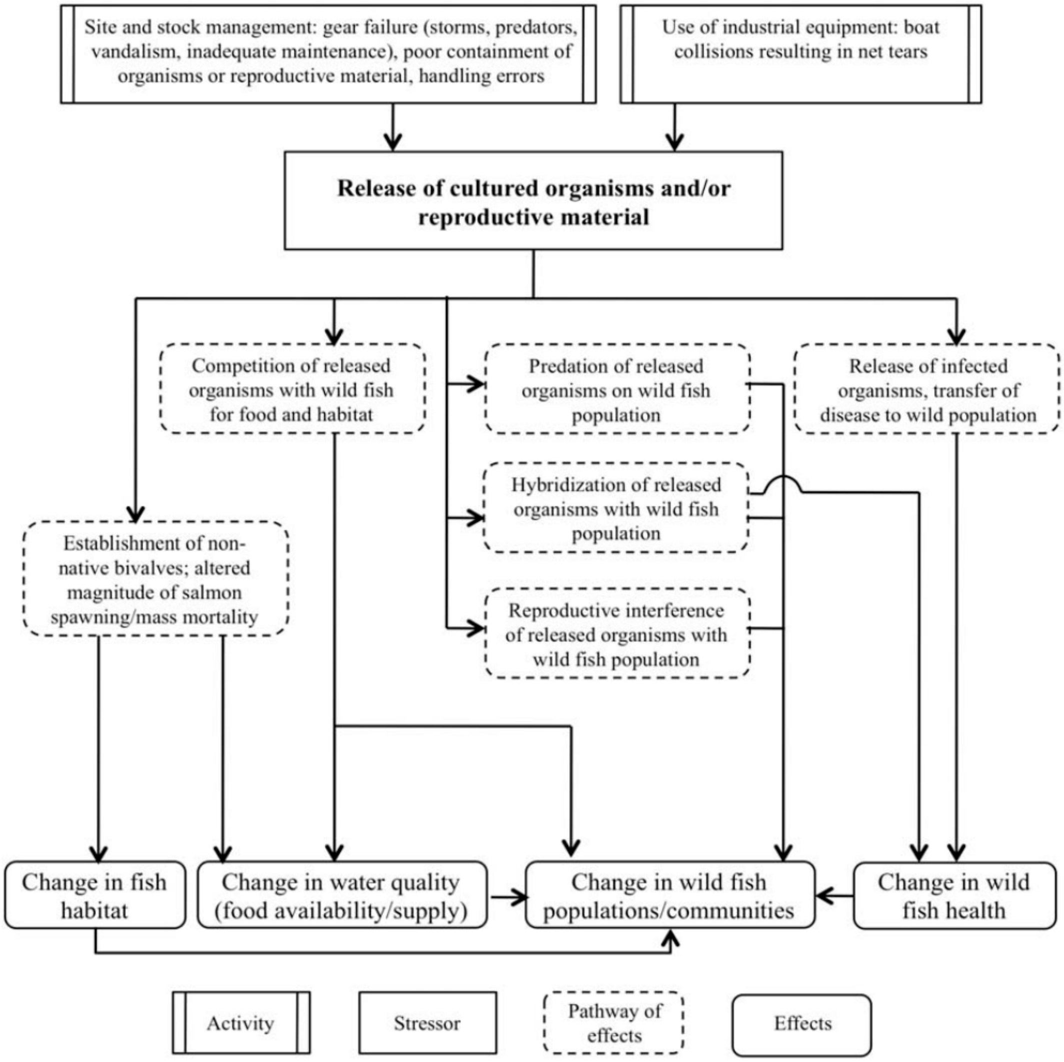


Fig. 2.2.2 The potential pathways of effects of released (escaped) farmed organisms on components of Canadian aquatic ecosystems (from Leggatt *et al.* 2010; http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/resdocs-docrech/2010/2010_019_e.pdf).

2.2.2 Research to Support Sustainable Aquaculture

Aquaculture regulatory research is undertaken primarily by DFO scientists who address priority regulatory knowledge gaps as identified by regulators and aquaculture management in the Department. To date, research has focused primarily on fish health management issues (*e.g.*, pathogen dispersal prediction models, fate and effect of sea lice treatments in the environment, developing bay management areas for new aquaculture sites, *etc*.) and addressing knowledge gaps for evaluating aquaculture siting questions (*e.g*., the fate of wastes on hard-bottom surfaces, oceanographic modelling of waste dispersal, bathymetry analysis in areas identified for new aquaculture sites). Knowledge gaps identified in the process of scientifically evaluating the pathways of effects also help to guide the identification of research priorities.

2.3 Japan

2.3.1 Legislative Framework for Risk Assessment of Aquaculture

Mariculture generates large amounts of nutrients and organic wastes, resulting in environmental deterioration in and around aquaculture facilities. In addition, mariculture has risks such as escapes of farmed marine animals and disease infections between farmed and wild marine species. Environmental impact assessment and risk assessment of aquaculture are to be important processes for conducting sustainable aquaculture in Japan.

Legislation of the license for aquaculture

The Fisheries Law is the principal law that regulates fishery activities. It is administered by the Ministry of Agriculture, Forestry and Fisheries (MAFF), although many tasks are delegated to prefectural governments. The Fisheries Law is the basis for granting licenses to Fisheries Cooperative Associations (FCA). A jury organized of publicly elected committees and those selected by the prefectural governor examines an application for a license in which the type and duration of mariculture, and location and extent of the farm are described, and submits a report to the governor. Based on the report, the governor decides whether the license should be granted (FAO, 2005). In 1999, the Law to Ensure Sustainable Aquaculture Production (ESAP) was enacted. This is the first law in Japan to specifically target aquaculture and is intended to reduce risks of aquatic animal diseases and to improve environmental conditions. The Law requires individual FCAs to develop and implement Aquaculture Ground Improvement Programs (AGIPs) and submit the Programs to the prefectural government (Yokoyama *et al*., 2006a).

Environmental assessment

In Japan, the legislative framework was constructed fundamentally to protect fisheries and mariculture environments from sewage and industrial effluents (Yokoyama and Yamamoto, 2008). There is no adequate legal framework for risk assessment processes for aquaculture. Even the ESAP does not require an assessment of the environment before the commencement of aquaculture. Therefore, for most of the fisheries grounds in Japan, there have been no cases of environmental impact assessments conducted prior to the establishment of aquaculture, and the scope of the ‘environmental assessment’ is focused on the monitoring of the environmental parameters and evaluation of the assimilative capacity. Here, assimilative capacity is the ability of an area to maintain a ‘healthy’ environment and ‘accommodate’ wastes (Fernandes *et al*., 2001).

The Environmental Impact Assessment (EIA) Law was enacted in 1997. Although the Law does not directly refer to aquaculture, local governments set Ordinances on EIA following the Law and some of them include aquaculture activities. In practice, however, no EIAs have been conducted for aquaculture.

Environmental quality standards

Within MAFF, the Fisheries Agency is responsible for preserving and managing marine biological resources and fishery production activities (FAO, 2005). The Fisheries Agency has recognized eutrophication as a serious threat to inshore fisheries, and requested the Japan Fisheries Resource Conservation Association (JFRCA) to devise Environmental Quality Standards (EQS) for inshore fishery grounds for environmental assessment. In 1983, JFRCA established EQS at coastal fisheries grounds (Table 2.3.1). Ten years after EQS were established, the Basic Environmental Law (1993) was enacted requiring the government to establish EQS to be achieved and maintained in public waters to protect human health and conserve the living environment. Although not specific to aquaculture, EQS take into consideration the potential health hazards associated with the intake of listed substances through drinking water and/or fish and shellfish.

The Law to Ensure Sustainable Aquaculture Production (1999) together with the Basic Guidelines to Ensure Sustainable Aquaculture Production (1999) set EQS, which are regulations designed to protect the environment of the water body and/or aquaculture organisms, based on three indicators: (1) dissolved oxygen (DO) content of water in fish cages, (2) acid volatile sulfide (AVS) content in the sediment, and (3) the occurrence of macrofauna under aquaculture facilities (Table 2.3.2). The farm environments are identified as healthy when the values of these indicators are within the thresholds. At the same time, EQS for critical environments, which are used to signal that urgent countermeasures are necessary, have been identified.

Table 2.3.1 Environmental quality standards (EQS) at coastal fisheries grounds (JFRCA, 2005).

Indicator	Criteria
Chemical oxygen demand of water	
General coastal areas	< 1 mg/L
Semi-enclosed embayments	< 2 mg/L
Nori culture grounds	< 2 mg/L
Total phosphorus of water	
1st fisheries class	< 0.03 mg/L
2nd fisheries class	< 0.05 mg/L
3rd fisheries class	< 0.09 mg/L
Total nitrogen of water	
1st fisheries class	< 0.3 mg/L
2nd fisheries class	< 0.6 mg/L
3rd fisheries class	< 1.0 mg/L
Dissolved oxygen	> 6 mg/L
(bottom water of embayments in summer)	(> 4.3 mg/L)
pH	7.8~8.4
Chemical oxygen demand of sediment	< 20 mg/g dry sediment
Acid volatile sulfides of sediment	< 0.2 mg/g dry sediment

Table 2.3.2 Environmental criteria adopted in the Law to Ensure Sustainable Aquaculture Production (ESAP).

Item	Indicator	Criteria for identifying healthy farms	Criteria for identifying critical farms
Water in cages	Dissolved oxygen	> 5.7 mg/L	< 3.6 mg/L
	Acid volatile sulfide	Less than the value at the point where the benthic oxygen uptake rate is	> 2.5 mg S/g dry sediment
Bottom environment	Benthos	Occurrence of macrobenthos throughout the year	Azoic conditions for more than 6 months

2.3.2 Current Status of Research on Environmental Assessment of Aquaculture

A practical way to implement ecosystem-based management of aquaculture is to evaluate aquaculture environments objectively and to conduct aquaculture within the range of assimilative capacity of surrounding waters. Several research projects have been conducted to monitor aquaculture environments, to estimate the assimilative capacity of aquaculture grounds, and to develop models for environmental assessments. These research projects were not adapted to formal environmental assessment processes. However, some of these have been referred to for developing the AGIPs under the ESAP.

Finfish culture

Research has been conducted in the following categories for assessing fish farm environments objectively in order to conduct fish farming within the assimilative capacity of surrounding environments.

Macrobenthic community

Quantitative analyses of macrobenthic communities in farming areas are available to validate the farming environments. Macrofauna are sensitive to changes in organic inputs, and they have been often used as a sensitive indicator in environmental monitoring of fish farms in Japan. A community negatively affected by fish farming is indicated by a reduction in species richness and/or species diversity, the appearance of dense populations of the opportunistic polychaete *Capitella* sp., which often results in the increase in total macrofaunal abundance, a decrease of large-sized species, and the disappearance of echinoderms.

Indices for suitable siting of fish farms

Studies have been conducted to develop guidelines for the suitable siting of fish farms and to determine the upper limit of fish production. Two indices, ED (Embayment Degree) and ISL (Index of Suitable Location), were proposed based on macrofauna studies and chemical factors of the water and sediment (Yokoyama *et al*., 2002a,b, 2004). From these studies, threshold values of benthic components were derived to classify fish farm environments as healthy, cautionary, or critical (Table 2.3.3).

Stable isotope analysis

Stable isotope analyses have been used to estimate the flux and fate of fish feed in fish farms (Yokoyama *et al*., 2006b, 2009). Waste feed and fecal matter in sediment trap materials and sediments can be quantified by using stable carbon and nitrogen isotope ratios. Based on this technique, the spatial extent of waste dispersal was estimated in a fish farming area. The optimum ration level was also assessed in a red sea bream farm to minimize waste feed.

Table 2.3.3 Threshold values of benthic components for fish farms (Yokoyama *et al*., 2004).

Benthic components	Cautionary condition	Critical condition
Sediment		
Total organic carbon	> 20 mg/g dry	> 30 mg/g dry
Total nitrogen	> 2.5 mg/g dry	> 4 mg/g dry
Total phosphorus	> 4 mg/g dry	> 6 mg/g dry
Chemical oxygen demand	> 30 mg/g dry	> 75 mg/g dry
Acid volatile sulfide	> 0.5 mg/g dry	> 1.5 mg/g dry
Macrobenthos		
Biomass	< 10 g/m^2	0
Density	< 1500 individuals/m^2	0
Number of species	< 20 /0.04 m^2	0

Numerical modeling

In Japan, many models are used to assess aquaculture environments and estimate the carrying capacity and assimilative capacity of aquaculture grounds. The Fisheries Agency requested JFRCA to examine assessment methods for aquaculture environments in the 1970s. In the examinations, JFRCA developed numerical models to simulate the aquaculture environments. Kishi *et al*. (1994, 1995, 2003) developed physical–biological coupled models for quantitative management of aquaculture. Takeoka *et al*. (1988) analyzed material cycles and the oxygen budget in a yellowtail (amberjack) farming area by using a numerical model. Omori *et al*. (1994) proposed a concept of maximal benthic oxygen uptake rate to estimate the assimilative capacity of aquaculture grounds. Based on the concept, Abo *et al.* (2006) were able to estimate the upper limit of organic matter loading in a fish farming area using a numerical model.

Oyster culture

Excessive culture density in terms of individual numbers per raft, which may lead to a shortage of natural phytoplankton feed for oysters, is a major problem. The means of intensive culture in terms of raft number per area is also an issue because oyster feces may deteriorate the sediment quality. Research has been conducted to estimate optimal production volume and culture density in order to achieve effective harvesting and environmental preservation. Numerical models have been developed to assess the oyster culture in Japan. Kobayashi *et al*. (1997) developed a population dynamics model for the Japanese oyster, *Crassostrea gigas*, to investigate the effects of oyster density, the distribution of mariculture rafts, and cultivation practices on the growth and development of the oysters. This model can provide a framework for predicting potential oyster yield from individual mariculture fields. In Hiroshima prefecture, an oyster culture model based on raft-scale cultivation was developed to estimate the most suitable culture density. Recently, Yamamoto *et al*. (2009) developed a numerical model expressing physiological processes of the oyster and estimated the appropriate culture density under the environmental conditions of Hiroshima Bay. As the culture density is not regulated in Japan, scientific results obtained from these studies can be a reliable source for local governments to provide to farmers as a guide on the appropriate density for sustainable oyster culture.

In Ago Bay, where pearl oyster culture has been conducted intensively for more than 100 years, a project team that consists of the local government, universities and public and civil research institutes has been formed to develop methods for the environmental remediation of the aquaculture grounds. The team has developed an automatic water quality measurement system and a numerical model to nowcast and predict the conditions. Anggara Kasih *et al*. (2008, 2009) also developed a model to assess sediment quality in the pearl oyster culture area in Ago Bay.

Nori culture

As seaweeds absorb nutrients from sea water and reduce eutrophication, it is regarded that seaweed culture has positive effects on the surrounding environment. So far, we have not considered it necessary to do a risk assessment for Nori culture. On the other hand, it has been observed recently that Nori culture is suffering nutrient poverty in seawater. In addition to a decrease in nutrient load from the land by a system of Area-wide Total Pollution Load Control and competition for nutrients with diatoms, the Nori crop is decreasing significantly. Therefore, models have been developed to predict the occurrence of diatom blooms and to predict the nutrient conditions at Nori culture grounds.

2.3.3 References

Anggara Kasih, G.A., Chiba, S., Yamagata, Y., Shimizu, Y. and Haraguchi, K. 2008. Modeling early diagenesis of sediment in Ago Bay, Japan: A comparison of steady state and dynamic calculations. *Ecol. Modell.* **215**: 40–54.

Anggara Kasih, G.A., Chiba, S., Yamagata, Y., Shimizu, Y. and Haraguchi, K. 2009. Numerical model on the material circulation for coastal sediment in Ago Bay, Japan. *J. Mar. Syst*. **77**: 45–60.

Abo, K. and Yokoyama, H. 2006. Assimilative capacity of fish farm environments as determined by benthic oxygen uptake rate: studies using a numerical model. *Bull. Fish Res. Agency* **19**: 79–87.

FAO (Food and Agriculture Organization of the United Nations). 2005. National aquaculture legislation overview: Japan. FAO Fisheries (Aquaculture). Fisheries Global Information System, FAO, Rome, Italy.

Fernandes, T.F., Eleftheriou, A., Ackefors, H., Eleftheriou, M., Ervik, A., Sanchez-Mata, A., Scanlon, T., White, P., Cochrane, S., Pearson, T.H. and Read, P.A. 2001. The scientific principles underlying the monitoring of the environmental impacts of aquaculture, *J. Appl. Ichthyol*. **17**: 181–193.

JFRCA (Japan Fisheries Resources Conservation Association). 2005. Water quality criteria for the protection of aquatic living resources (the 2005 edition). Japan Fisheries Resources Conservation Association, Tokyo, Japan (in Japanese).

Kishi M.J., Uchiyama, M. and Iwata, Y. 1994. Numerical simulation model for quantitative management of aquaculture. *Ecol. Modell*. **72**: 21–40.

Kishi, M.J. and Uchiyama, M. 1995. A three dimensional numerical model for a mariculture nitrogen cycle: Case study in Shizugawa Bay, Japan. *Fish. Oceanogr*. **4**: 303–316.

Kishi, M.J., Higashi, N., Takagi, M., Sekiguchi, K., Otobe, H., Furuya, K. and Aiki, T. 2003. Effect of aquaculture on material cycles in Otsuchi Bay, Japan. *Otsuchi Mar. Sci*. **28**: 65–71.

Kobayashi, M., Hofmann, E.E., Powell, E.N., Klinck, J.M. and Kusaka, K. 1997. A population dynamics model for the Japanese oyster, *Crassostrea gigas*. *Aquaculture* **149**: 285–321.

Omori, K., Hirano, T. and Takeoka, H. 1994. The limitations to organic loading on a bottom of a coastal ecosystem. *Mar. Poll. Bull*. **28**: 73–80.

Takeoka, H., Hashimoto, T. and Yanagi, T. 1988. A numerical model of the material cycling in the ground of yellowtail culture. *Bull. Japanese Soc. Fish. Oceanogr.* **52**: 213–220.

Yamamoto, T., Maeda, H., Matsuda, O. and Hashimoto, T. 2009. Effects of culture density on the growth and fecal production of the oyster *Crassosterea gigas*. *Nippon Suisan Gakkaishi* **75**: 230–236 (in Japanese with English abstract).

Yokoyama, H., Nishimura, A. and Inoue, M. 2002a. Influence of aquaculture and topographic conditions on the macrobenthos and the sediment in fish farms along the Kumano-nada coast. *Bull. Japanese Soc. Fish. Oceanogr*. **66**: 133–141 (in Japanese with English abstract).

Yokoyama, H., Nishimura, A. and Inoue, M. 2002b. Evaluation of fish farm environments by identifying community types of the macrobenthos. *Bull. Japanese Soc. Fish. Oceanogr*. **66**: 142–147 (in Japanese with English abstract).

Yokoyama, H., Inoue, M. and Abo, K. 2004. Estimation of the assimilative capacity of fish-farm environments based on the current velocity measured by plaster balls. *Aquaculture* **240**: 233–247.

Yokoyama, H., Abo, K. and Ishihi, Y. 2006b. Quantifying aquaculture-derived organic matter in the sediment in and around a coastal fish farm using stable carbon and nitrogen isotope ratios. *Aquaculture* **254**: 411–425.

Yokoyama, H. and Yamamoto, K. 2008. Chapter 5.1, Japan, pp. 69–79 *in* EIA and Monitoring in Aquaculture *edited by* M. Phillips, Network of Aquaculture Centres in Asia-Pacific, Jatujak, Thailand.

Yokoyama H., Takashi, T., Ishihi, Y. and Abo, K. 2009. Effects of restricted feeding on growth of red sea bream and sedimentation of aquaculture wastes. *Aquaculture* **286**: 80–88.

Yokoyama, H., Abo, K., Ikuta, K., Kamiyama, T., Higano, J. and Toda, S. 2006a. Chapter 4. Japan, pp. 71–89 *in* The Role of Aquaculture in Integrated Coastal and Ocean Management: An Ecosystem Approach *edited by* J.P. McVey, C.-S. Lee, and P.J. O’Bryen. The World Aquaculture Society, Baton Rouge, Louisiana, USA.

2.4 Republic of Korea

2.4.1 Legislative Framework for Risk Assessment of Aquaculture

Korea has experienced a rapid increase in pollutant inputs from land-based sources into coastal waters, and high degradation of coastal habitats due to intensive coastal development since the 1970s. Population growth rates in some coastal cities were three times higher than the national average. Pollution loads in terms of biological oxygen demand (BOD) increased about 40% during the last decade, and coastal wetlands decreased 20% through reclamation projects. Those land-based activities caused the deterioration of water quality, the increase in outbreaks of red tides, and the decrease of major spawning and nursery sites for marine living resources. Not until the mid-1990s did marine environmental protection come on the public agenda. Large-scale red tide outbreaks and oil spills in the mid-1990s led the Korean government to establish strategic action plans and policies to address these issues. Serious ecological and economic damage from these environmental disasters contributed to raising public awareness on marine ecosystem protection. In 1995, the Korean government initiated the National Clean Water Action Plan to improve coastal water quality and to protect coastal environments from land-based activities. The core of the Plan is the construction of sewage treatment plants in coastal areas. With the establishment of new ocean governance in 1996, the Korean government has provided a firm basis for systematic approaches to managing coastal resources and the marine ecosystem.

The establishment of the National Comprehensive Plan was the first step in managing and protecting the marine environment and resources in a cooperative manner among relevant authorities. It was the first strategic plan for marine environmental management and a budget was allocated for the expansion of publicly-owned pollutant treatment facilities. The Korean government has already established and implemented national initiative and action plans to protect the marine environment, even though there has not been a single integrated action plan for implementation.

The Korean government started to reinforce policies for ecosystem and habitat protection in coastal areas in 2006 through the enactment of the Law on the Conservation and Management of Marine Ecosystems, the amendment of *Public Waters Reclamation Act* and the *Coastal Management Act,* and through the strict application of environmental impact assessments on coastal utilization and development projects. These actions are to prevent habitat degradation, loss of marine living resources, decreases in fisheries and to ensure sustainable development, based on a healthy marine environment, using an ecosystem-based management (EBM) approach (Fig. 2.4.1).

The government's goal is to protect and reconstruct coastal habitats, secure fishable and swimable environments, and ensure sustainable use of coastal resources, living and non-living. Primary approaches to achieve the goals are through "Anti-degradation of the current environment and ecosystem condition" and through the "Improvement of deteriorated coastal environment". Objectives for attaining these goals are classified into the enhancement of ecosystem health, improvement of water and sediment environment qualities, and the strengthening of the legal and institutional bases (Fig. 2.4.2).

EBM deals with a full range of land-based pollutants and activities. Setting a geographic boundary is required to effectively control land-based activities and enforce legal and institutional arrangements.

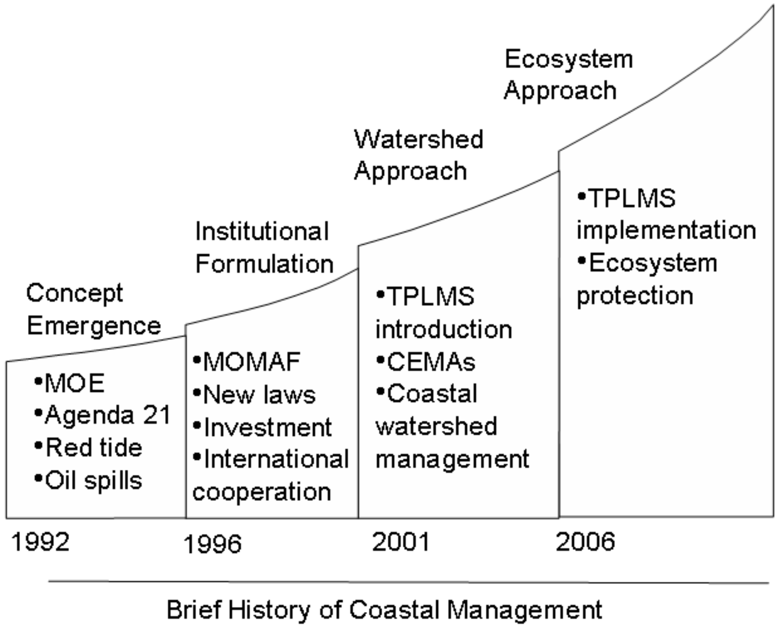


Fig. 2.4.1 Brief history of coastal and marine environment management. MOE = Ministry of Environment, MOMAF = Ministry of Maritime Affairs and Fisheries, TPLMS = Total Pollutant Land Management System, CEMAs = Coastal Environment Management Areas.

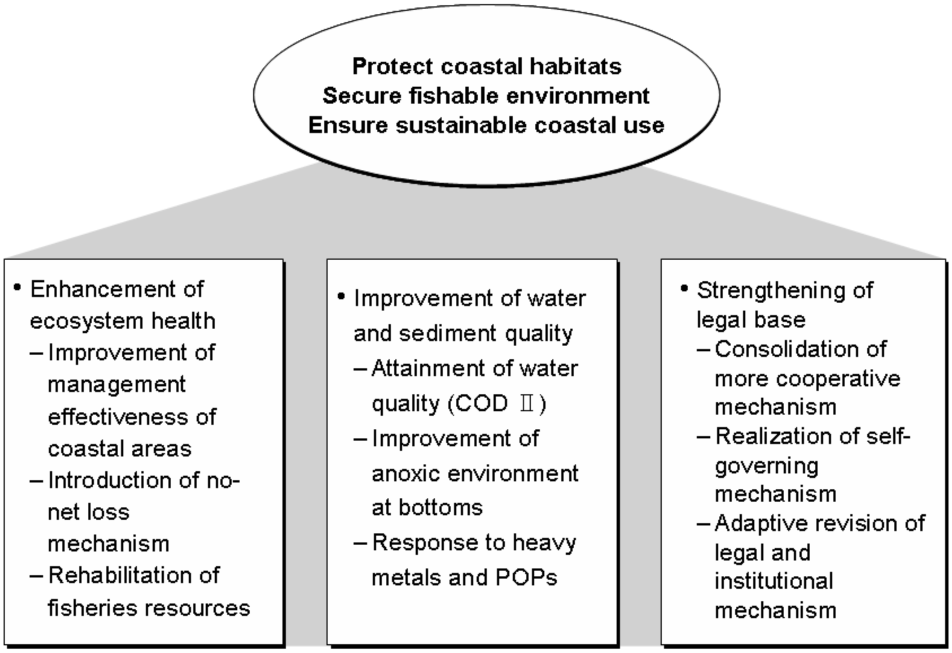


Fig. 2.4.2 Schematic diagram of goals and objectives. COD = chemical oxygen demand, POPs = persistent organic pollutants.

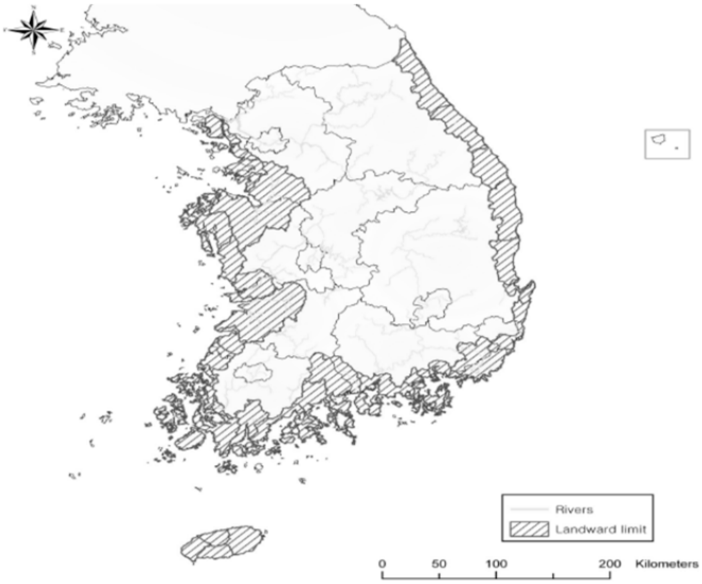


Fig. 2.4.3 Geographic coverage of ecosystem-based management (EBM) areas in Korea.

Boundary setting for EBM implementation is necessary for the effective allocation of resources and budgets and for the clarification of authority and roles of relevant entities. The geographic boundary covers both inland and sea areas (Fig. 2.4.3). The sea area for implementation extends the Exclusive Economic Zone from the coastlines. The land area covers everything from the high water mark of coastlines to the landward limit of coastal watersheds. The geographic boundary of EBM is similar to that of the National Program of Action.

EBM includes environmental (water quality and sediment quality) management measures, resources (living resources and space utilization) management measures, and institutional measures (human, organizational, and financial resources). The EBM approach controls the pollution loads from land areas, and the activities causing alteration or degradation of habitats and the ecosystem. The targets for pollutant inflow control into the marine environment include sewage, persistent organic pollutants, radioactive materials, heavy metals, oils/hydrocarbons, nutrients, and litter. EBM covers the protection of: coastal habitats, the coastline from mineral and sediment extraction and coastal reclamation, and tidal mudflats.

2.5 Russia

2.5.1 Legislative Framework for Risk Assessment of Aquaculture

Aquaculture research and the commercial cultivation of marine species were widely developed in Russian seas in the 1970s and 1980s. This was the first stage of mariculture formation as a new branch in Russian scientific and fish farming development. Russian marine aquaculture production amounted to 5–6 thousand tons only, mainly due to Russian Far East kelp culture. At the end of the 1990s practically all mariculture enterprises were closed due to economic reforms. As such, reliable aquaculture statistics became unavailable. As of 2005, mariculture has only been developed to a small degree by the domestic industry. By some estimates, Russia occupies 14th place in algae cultivation (3 thousand tons) and 28th place in fish and invertebrate cultivation (68 thousand tons). There are 45 salmon hatcheries in Russia that, in 2006, produced about 700 million newly hatched fish. As of 2005, only approximate estimates of mariculture development in the regions of Russia are available.

Currently in Russia, fishery and aquaculture activities are under the jurisdiction of the Federal Agency for Fisheries (FAF). The territorial administrations of FAF are in each federal district. Management and all stakeholder activities are governed by the Fishery Law, and although an Aquaculture Law has been elaborated over the last few years, it has not yet been adopted. Additionally, the Wildlife Protection Law and Veterinary Legislation are binding on farmers.

The State standards and requests are issued through several ministries and agencies under the government of Russia (FAF, Ministry of Nature Protection, and others). There are several law-making documents regulating environmental quality, habitat alteration and control for seafood safety. The List of Maximal Permissible Concentrations for Fisheries Grounds and Federal Sanitary Norms and Rules are the primary legal documents. In these documents the federal norms for toxic substances, heavy metals, organic pollutants and others have been established. Mariculture activities in Russia, whether for enhancement or industrial fish farming purposes, are managed legislatively at a regional level, rather than at a national level. Regional regulations related to mariculture are often grouped with fisheries regulations, and are specific to address regional priorities. Thus, there is no over-arching legislative or regulatory framework for mariculture. According to all accounts this is the restrictive factor for mariculture activity in Russia.

2.5.2 Research to Support Sustainable Aquaculture

In the Far East, and North Sea and Black Sea basins, industrial rearing of high-value mariculture species such as mussels, scallops, sea cucumbers, mullets, Atlantic cod and others has been developed on an experimental basis. Fifteen fish species and sub-species that are included in the Red Data Book of the Russian Federation (2001) were artificially reproduced at aquaculture enterprises (FAO, 2005).

Russia enjoys a large ocean shelf. However, about 70% of it falls within the Arctic seas, and these zones are not favorable for commercial cultivation (Makoedov and Kozhemyako, 2005). The main regions for mariculture research are located in the southern region of the Sea of Azov and Black Sea, in the northern region of the Barents and White seas, and in the Russian Far East. Mussels, kelp, herring and salmon are cultivated in the White Sea region. Great progress has been achieved in the cultivation of mussels and oysters, and fish-pond cultivation of salmon, sturgeon and mullet in the Black Sea. Sturgeon cultivation was of great importance in Black Sea, Sea of Azov, and Caspian Sea. Biotechnologies of fish-pond and ranching cultivation of sturgeon have been developed in the Caspian Sea. In the Russian Far East, bivalve biotechnologies for scallops, Pacific oysters, mussels, and sea cucumbers have been developed. Sea urchin and king crab biotechnologies are under way. There are more thirty aquaculture farms in Primorye, with the major cultivated species being scallops, mussels, sea cucumbers and kelp (Gavrilova, 2005).

2.5.3 References

FAO (Food and Agriculture Organization). 2005. Report of the First Meeting of Directors of the Network of Aquaculture Centres in Central-Eastern Europe (NACEE). FAO Fisheries Report No. 774, Rome, 195 pp. ftp://ftp.fao.org/docrep/fao/008/y5923b/y5923b.pdf

Gavrilova, G.S. 2005. The current status of research and problems of invertebrate mariculture in the Russian Far East. Topic Session 7, PICES Fourteenth Annual Meeting, Vladivostok, Russia.

Makoedov A.N. and Kozhemyako O.N. 2005. Foundations of fisheries policy in Russia. http://www.npacific.ru/np/library/publikacii/makoedov/04_1.htm

2.6 United States of America

2.6.1 Legislative Framework for Risk Assessment of Aquaculture

Although shellfish aquaculture has taken place along the west coast of the United States for at least 90 years, marine aquaculture is a recent endeavor in the U.S. relative to some of the other PICES member countries. As a result, no comprehensive federal framework for marine aquaculture was established and activities are covered under separate regulations administered by at least six federal agencies. Further, licensing and permitting requirements can vary by state within 3 miles of the coastline and individual states and local governments may have additional legal provisions. Permits have usually been granted for individual activities and requirements are often not specific to aquaculture due to the precedence of other marine and coastal activities. This has resulted in constraints and some conflicts over marine aquaculture development (Aspen Corporation, 1981; NRC, 1992; DeVoe, 2000). Nonetheless, activities currently result in federal action by the U.S. Army Corps of Engineers (ACOE) and U.S. Environmental Protection Agency (EPA) which assert jurisdiction under the *Rivers and Harbors Act* and the *Clean Water Act*. This, in turn, requires consultation with the U.S. Fish and Wildlife Service (USFWS) and National Oceanic and Atmospheric Administration (NOAA), with their authority under the *Endangered Species Act*, *Magnuson Stevens Fishery Conservation and Management Act*, *Marine Mammal Protection Act*, *Coastal Zone Management Act*, and *Lacey Act*. EPA also regulates discharges of wastewater from aquaculture facilities and the use of pesticides. Other activities are regulated by USDA (U.S. Department of Agriculture) Animal and Plant Health Inspection Service (APHIS) which has authority over vaccine approvals and animal movement permitting, including importation of invasive or potentially injurious species (*Animal Health Protection Act*), along with USFWS. The Food and Drug Administration (FDA) has authority over the use of drugs in aquaculture facilities (*Federal Food, Drug and Cosmetic Act*). The *National Aquaculture Act*, designed to coordinate federal agency activities and promote aquaculture, was passed in 1980 and was most recently re-authorized in 2008. The Joint Subcommittee on Aquaculture (JSA) composed of participants from federal agencies involved in aquaculture was created to serve as an interagency coordinating group and is currently developing a national research and development strategic plan for U.S. aquaculture.

Within this broader regulatory environment, formal risk assessments for marine aquaculture activities are only infrequently conducted. A recent example is a quantitative and qualitative risk analysis for infectious salmon anemia virus (ISAV) currently being conducted by USDA/APHIS as part of regulation development (USDA APHIS, 2002). Risk assessments that evaluate disease issues for both marine fish and shellfish aquaculture are only briefly mentioned here, but are considered separately under this Subcommittee's final term of reference. A set of guidelines for conducting ecological risk assessments for marine fish aquaculture based on a common analytical framework developed by the World Health Organization was proposed by Nash *et al*. (2005), but risk assessments for aquaculture are still generally conducted through the permit process which varies from state to state and by federal agency. Environmental effects are often considered in the process of developing an environmental impact statement (EIS) or environmental assessment (EA) for specific projects or for specific practices. Conducting an EIS or EA is in fulfillment of the *National Environmental Policy Act* (NEPA). Some examples from the U.S. west coast are an EIS and supplemental EIS for applying the pesticide carbaryl for burrowing shrimp control in oyster aquaculture (WDOE and WDF, 1992), an EIS for adding gravel to shellfish aquaculture beds (Newman and Cooke, 1988; Thompson, 1995), an EA for shellfish mariculture in Humboldt Bay, California (Jones and Stokes, 2004), and an EIS for salmon net pen culture (WDF, 1990). Net pen discharge permits are updated and given public review every 5 years and are currently about to be revised the third time. This allows any new issues to be dealt with and may also be used to alter existing monitoring protocols to conform with new technology. Permitting for shellfish aquaculture has most often taken place at the state or local jurisdictional level in the past, in part because these activities rarely crossed state lines, but also because shellfish aquaculture activities were in existence before most of the broader environmental protection laws listed above were enacted in the 1970s. The ACOE issued a revised nationwide permit for all existing shellfish aquaculture activities in 2007 which required new reporting activities. This allowed for regional conditions to be established by the states, and details remain under discussion for some U.S. west coast states.

There are, however, limitations to aquaculture in the nearshore marine environment due to political, economic and environmental constraints. With an expansion of the human population in coastal areas, space conflicts with other activities, and resource uses and conflicts with coastal residents over views from shorefront property and beach access have become pressing issues. This has resulted in recent incentive and interest in evaluating the potential for conducting aquaculture in offshore areas in the Exclusive Economic Zone and an *Offshore Aquaculture Act* was first proposed to the U.S. Congress in 2007 (NOAA, 2007). While this legislation has not yet been enacted, and there is still no federal permitting process in place for these activities, several moderately successful trial operations have taken place (Langan, 2004; Cheney *et al*., 2010; Langan, 2010). There continues to be great interest in offshore aquaculture and efforts to address regulatory issues such as actively pursuing marine spatial planning for offshore aquaculture and alternative energy development (Halpern *et al*., 2008; Foley *et al*., 2010).

2.6.2 Current Status of Research on Environmental Assessment of Aquaculture

Most ecological monitoring of existing aquaculture projects has focused on determining the extent of adverse impacts to the benthos since these are easiest to observe and measure. Many aquaculture sites, especially floating net pens and suspended shellfish culture rafts, experience rapid and large temporal fluxes of ambient water quality conditions and fluxes in the presence of mobile pelagic and demersal species making it more practical to monitor physiochemical sediment characteristics such as sulfide or total organic carbon concentrations and benthic infauna species abundance and diversity. The latter are sessile and most likely to be adversely influenced by particulate organic enrichment beneath or near the aquaculture sites. While there has been increased emphasis placed on evaluating ecosystem-level effects and some of these have been researched and incorporated into guidelines and plans (NOAA, 2007), they have not yet been put directly into practice in evaluating sites, and gaps remain in the ability to quantitatively do this (Soto *et al*., 2008).

Shellfish

Recent interest in the environmental effects of individual farming practices and heightened concerns regarding endangered species of salmon, sturgeon, and other species, particularly those that utilize estuaries along the U.S. west coast, has resulted in some significant recent research on the ecological role of shellfish aquaculture in the marine environment (reviewed in Dumbauld *et al*., 2009; NRC, 2010). Bivalve shellfish influence the estuarine environment in three ways:

1. shellfish process food and produce organic wastes,
2. shellfish and the materials on which they are anchored or held and cultured modify water flow and add structural habitat,
3. culture practices like planting and harvesting cause temporary pulsed disturbances to other organisms and their habitat.

Most attention and studies have focused on the first concern. Shellfish produce biodeposits that can reduce grain size and increase organic content of sediments underneath or within (for bottom culture) the culture site. This, in turn, can transform the benthic community, usually dominated by suspension feeders, into a less diverse community dominated by opportunistic deposit feeders. For bottom cultured shellfish, it is difficult to distinguish the effect of biodeposition from the effect of structure, and in U.S. west coast estuaries none of these extreme cases of enrichment have been documented. Most studies have shown enhanced diversity in bottom cultured oyster habitat relative to that in open unstructured habitat (Hosack *et al*., 2006; Ferraro and Cole, 2007). The density of shellfish planted and the physical context of the environment into which they are placed are most important and the only observable effects seen in the few studies conducted on suspended culture suggested that biodeposits are not as significant as those recorded for finfish culture and apparently dispersed offsite (Brooks, 2004; Harbin-Ireland, 2004). Local near-field effects of bivalves as filter feeders on phytoplankton have been documented in U.S. west coast systems, but models which have been widely developed to track effects at the estuarine system level (such as those discussed above for Japan), usually in the context of establishing a carrying capacity for aquaculture operations, have not been applied. An exception is for ground cultured oysters in Willapa Bay, Washington, where recent research suggests that these shellfish, which have been cultured on a broad scale for about 100 years in this estuary, can have such an effect by reducing growth of those oysters planted farther away from the estuary mouth (Banas *et al*., 2007; Wheat, 2010).

From a regulatory standpoint, another important issue along the U.S. west coast continues to be the effect of shellfish aquaculture practices on estuarine habitat for other species. Effects on habitat are evaluated against existing habitat and eelgrass (*Zostera marina*) is viewed as one of the most important forms of structured habitat, providing food and refuge for fish and invertebrates, including juvenile salmon. Research to date suggests that disturbance to eelgrass due to shellfish aquaculture depends on the activity, but in most cases results in relatively short-term loss and recovery occurs within the timeframe of a grow-out cycle for bottom cultured oysters (Tallis *et al*., 2009). Structure provided by oysters appears to function similarly to eelgrass for small epifauna while use by larger fish and invertebrates depends on species and even life history stage (Dumbauld *et al.*, 2009). Research on the effects of clam aquaculture, including that for the large infaunal geoduck clam, is underway (Straus *et al*., 2008; Ruesink and Rowell, 2012). As for the effect of shellfish on nutrients and phytoplankton, spatial scale seems like a very important management consideration and research at this scale should contribute to more informed management and best management practices for shellfish aquaculture. Disease interactions for shellfish mariculture have been significant (recent west coast examples include Denman Island disease, haplosporidiosis, hemic neoplasia, and larval hatchery mortalities associated with vibrios) and have been primarily regulated *via* quarantines and inspections with interstate agreements and transfer permits. Though an industry-sponsored high health program has been discussed, it has not been implemented. The U.S. west coast shellfish aquaculture industry has actively supported most of the above research, and developed and continue to update its own environmental policy, codes of practice and research plan (PCSGA, 2001; PSI, 2005).

Finfish

Research, risk assessment and management of the impacts of marine fish aquaculture along the west coast of the United States has focused on net pen culture of Atlantic salmon (*Salmo salar*) in Washington State. It is the only species currently commercially reared in that area. Environmental risks of rearing Atlantic salmon, a non-native species, were quantitatively considered during a formal NOAA risk assessment expert workshop and resulting publication (Nash, 2003) that addressed all possible risks and assigned relative risk rankings. In this work, the impact on the sediments beneath net pen farms from biodeposits, and the accumulation of heavy metals (zinc and copper from fish feed and net antifoulant, respectively), were considered to be the highest risks. Numerous other risks were evaluated but either assigned low or very little to no risk (see Table 2.6.1).

As with shellfish culture, concerns have been voiced about the impacts of increased nutrients from waste feed and feces to the benthos and dissolved nutrient wastes to the water column. Unlike shellfish culture which, at least at harvest, represents a net removal of macronutrients from the culture area, fed culture of fish in pens results in a net production of wastes into the ecosystem that must be assimilated or buried by sedimentation. Dissolved wastes, typically of ammonia nitrogen and relatively small amounts of urea for salmon, are rapidly advected away from the farm site in water currents. Ammonia nitrogen is rapidly converted to nitrate in any oxygenated aquatic environment by bacteria and can be utilized by phytoplankton if it remains in the photic zone or, if not, it is mixed into the deep layer. As a conservative regulatory measure, net pens in Washington State have been restricted to non-nutrient-sensitive marine areas (Rensel Associates and PTI Environmental Services, 1991) where the effects of discharge dissolved inorganic nitrogen or urea are unlikely to result in any additional phytoplankton biomass, either beneficial or harmful (SAIC, 1996; Anderson *et al*., 2008).

Table 2.6.1 List of U.S. west coast salmon aquaculture interactions and qualitative assessment of risk associated with each (adapted from Nash, 2003).

Environmental interaction	Effect	Risk
Biodeposits from farm beneath net pens	Increase in total volatile solids and decreased redox potential in sediments. Changes to benthic infaunal invertebrate community.	Most
Accumulation of copper and zinc in the sediments	Toxic to other organisms above apparent effects threshold concentrations.	Most
Low dissolved oxygen in the water column	Physiology of other organisms, but farmed salmon themselves are the species most sensitive and likely to be affected.	Low
Hydrogen sulfide and ammonia in the water column	Toxic to other organisms	Low
Algal bloom enhancement from dissolved nutrients	Toxic to other organisms if a harmful algal bloom is influenced. Otherwise, can influence the biomass of benign algae with variable results.	Low
Organic wastes and fouling drop-off	Changes to the epifaunal and infaunal community	Low
Proliferation of human pathogens	Human pathogenicity	Low
Proliferation of fish and shellfish pathogens	Effects on wild fish and shellfish	Low
Displacement of wild salmon in the market	Economic impact to fishers	Low
Escape of cultured non-native species	Hybridization with native salmon, colonization of wild salmon habitat, competition for food, predation on indigenous species	Very low to none
Release of antibiotic resistant bacteria	Disease effects on native salmonids	Very low to none
Other impacts on human health and safety	Heavy metal contamination, residual medicines and drugs, and biological hazards in farm products. Rendered animal proteins, genetically modified ingredients and other additives in food. Transgenic farm fish, workers safety, navigational hazards, and impact on nearby property values	Very low to none

The Washington State Department of Natural Resources adopted Interim Guidelines for Management of net pen culture that were promulgated in 1986 (SAIC, 1986) as legal requirements for their aquatic lands leases in the 1980s. Over time, some of the required environmental monitoring was found to be of little value, such as water column nutrient impact sampling, because the results were too variable and not really of consequence since commercial pens were all located in waters naturally replete with nitrogen and phosphorous, as discussed in the Washington State programmatic EIS on floating fish culture and its technical appendices (Rensel, 1989; WDF, 1990).

Other risks, including proliferation of human and fish pathogens and heavy metal contamination from feed, have been evaluated (Table 2.6.1, see Nash 2001, 2003 for review). Biodeposits from salmon farms have been shown to settle to the benthos, increase sediment sulfide, lower redox potential and influence the benthic community in a somewhat complex but predictable manner. Changes have been shown to occur most strongly beneath the culture operations, but have been noted as far away as 225 m several decades ago in some poorly sited and operated farms which are no longer in production. Since 1996 all farms are only allowed a 30-m sediment impact zone around the cages and at the perimeter of that zone background conditions of total organic carbon, zinc and copper must meet background reference conditions. If a farm site fails then additional benthic infauna sampling must be conducted at those same locations and statistically compared to reference area results. When these same organic particles are distributed farther away by stronger currents or sediment resuspension, they are also capable of biological enrichment, *i.e.*, the “halo” effect around any organic discharge source in marine waters (Pearson and Rosenberg, 1978) which may result in increased diversity and abundance of infauna or higher food web organisms, including marine birds that feed on biofouling on the pens and benthic organisms near the cages, resulting in higher marine bird densities than in nonfish farming areas nearby (Rensel and Forster, 2007).

When wastes reach the benthos they are assimilated first, in an aerobic manner by aerobic bacteria, infauna and other organisms. If the rate of particulate carbon bearing wastes exceeds the ability of that community to assimilate, the system slowly shifts to an anaerobic system where anaerobic sulfur reducing bacteria replace the aerobes and oxygen dependent macroinfauna (*e.g.*, polychaete worms). Management and regulatory guidelines are thus constructed to limit the spatial extent of this impact and the 30-m sediment impact zone limit around the pens usually results in aerobic sediments, even under the middle of the cages. Maintenance of an active and diverse benthic infauna helps speed up the assimilation of wastes through bioturbation, *i.e.*, burrowing through the sediments that increases the supply rate of dissolved oxygen from the overlying water/sediment boundary.

Relatively rapid chemical and biological remediation has been shown to occur naturally during fallow periods at most affected sites, depending on the currents and physical conditions in the affected area (Brooks and Mahnken, 2003a; Brooks *et al*., 2003). Zinc is an essential trace element which is often added to the feed for salmon nutrition and while the sediment quality criteria for this element (270 μg zinc/g dry sediment) have been shown to be exceeded in rare cases, the degree of risk has been more recently reduced by changes in feed formulations (Brooks and Mahnken, 2003b). After 15 years of periodic monitoring at all net pen sites in marine waters of Washington State, no violation of the sediment standards for zinc or copper have ever been recorded (J. Rensel, pers. comm. and annual reports to Washington Department of Ecology). Disease interactions between wild and farmed salmon are not considered of great significance in Washington State because most diseases appear to be limited to the farmed fish or are endemic in wild fish populations. Sea lice infection, which is of concern elsewhere (Marty *et al.*, 2010) is extremely rare in Washington State, primarily due to low salinity.

2.6.3 References

Anderson, D.M., Burkholder, J.M., Cochlan, W.P., Glibert, P.M., Gobler, C.J., Heil, C.A., Kudela, R.M., Parsons, M.L., Rensel, J.E.J., Townsend, D.W., Trainer, V.L. and Vargo, G.A. 2008. Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States. *Harmful Algae* **8**: 39–53.

Aspen Corporation. 1981. Aquaculture in the United States: Regulatory constraints. Report to the U.S. Fish and Wildlife Service, Washington, DC, 51 pp.

Banas, N.S., Hickey, B.M., Newton, J.A. and Ruesink, J.L. 2007. Tidal exchange, bivalve grazing, and patterns of primary production in Willapa Bay, Washington, USA. *Mar. Ecol. Prog. Ser.* **341**: 123–139.

Brooks, K.M. 2004. The fouling community found in association with the intensive raft culture of *Mytilus edulis galloprovincialis* in Totten Inlet, Washington. Report to the National Oceanic and Atmospheric Administration, Seattle, WA.

Brooks, K.M. and Mahnken, C.V.W. 2003a. Interactions of Atlantic salmon in the Pacific northwest environment II. Organic wastes. *Fish. Res.* **62**: 255–293.

Brooks, K.M. and Mahnken, C.V.W. 2003b. Interactions of Atlantic salmon in the Pacific Northwest environment III. Accumulation of zinc and copper. *Fish. Res.* **62**: 295–305.

Brooks, K.M., Stierns, A.R., Mahnken, C.V.W. and Blackburn, D.B. 2003. Chemical and biological remediations of the benthos near Atlantic salmon farms. *Aquaculture* **219**: 355–377.

Cheney, D., Langan, R., Heasman, K., Friedman, B. and Davis, J. 2010. Shellfish culture in the open ocean: Lessons learned for offshore expansion. *Mar. Technol. Soc. J.* **44**: 55–67.

DeVoe, M.R. 2000. Marine aquaculture in the United States: A review of current and future policy and management challenges. *Mar. Technol. Soc. J.* **34**: 5–17.

Dumbauld, B.R., Ruesink, J.L. and Rumrill, S.S. 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: A review with application to oyster and clam culture in West Coast (USA) estuaries. *Aquaculture* **290**: 196–223.

Ferraro, S.P. and Cole, F.A. 2007. Benthic macrofauna-habitat associations in Willapa Bay, Washington, USA. *Estuar. Coast. Shelf Sci.* **71**: 491–507.

Foley, M.M., Halpern, B.S., Micheli, F., Armsby, M.H., Caldwell, M.R., Crain, C.M., Prahler, E., Rohr, N., Sivas, D., Beck, M.W., Carr, M.H., Crowder, L.B., Duffy, J.E., Hacker, S.D., McLeod, K.L., Palumbi, S.R., Peterson, C.H., Regan, H.M., Ruckelshaus, M.H., Sandifer, P.A. and Steneck, R.S. 2010. Guiding ecological principles for marine spatial planning. *Mar. Policy* **34**: 955–966.

Harbin-Ireland, A.C. 2004. Effects of oyster mariculture on the benthic invertebrate community in Drakes Estero, Pt. Reyes Peninsula, California. M.S. thesis, University of California, Davis, CA.

Halpern, B.S., McLeod, K.L., Rosenberg, A.A. and Crowder, L.B. 2008. Managing for cumulative impacts in ecosystem-based management through ocean zoning. *Ocean Coast. Mngmt.* **51**: 203–211.

Hosack, G.R., Dumbauld, B.R., Ruesink, J.L. and Armstrong, D.A. 2006. Habitat associations of estuarine species: Comparisons of intertidal mudflat, seagrass (*Zostera marina*), and oyster (*Crassostrea gigas*) habitats. *Estuaries Coasts* **29**: 1150–1160.

Jones and Stokes Associates, Inc. 1994. Biological assessment and essential fish habitat analysis of Coast Seafoods mariculture operations in Humboldt Bay, California. 86 pp.

Langan, R. 2004. Balancing marine aquaculture inputs and extraction: Combined culture of finfish and bivalve molluscs in the open ocean. *Bull. Fish. Res. Agency* **Suppl. 1**: 51–58.

Langan, R. 2010. Technology needs for improved operational efficiency of open ocean cage culture. *Mar. Technol. Soc. J.* **44**: 47–54.

Marty, G.D., Saksida, S.M. and Quinn, II, T.J. 2010. Relationship between farm salmon, sea lice, and wild salmon populations. *Proc. Natl. Acad. Sci. U.S.A.* **107**: 22,599–22,604.

Nash, C.E. (Ed.) 2001. The net-pen salmon farming industry in the Pacific Northwest. U.S. Dept. of Commerce. NOAA Technical Memorandum, NMFS-NWFSC-49, 125 pp.

Nash, C.E. 2003. Interactions of Atlantic salmon in the Pacific Northwest VI. A synopsis of the risk and uncertainty. *Fish. Res.* **62**: 339–347.

Nash, C.E., Burbridge, P.R. and Volkman, J.K. 2005. Guidelines for ecological risk assessment of marine fish aquaculture. NOAA Technical Memorandum. U.S. Dept. of Commerce, NOAA NMFS-NWFSC-71, 90 pp.

Newman, J.R. and Cooke, W.A. 1988. Final environmental impact statement for the enhancement of hardshell clam production by beach gravelling. Washington Dept. of Fisheries, Olympia, WA.

NOAA (National Oceanic and Atmospheric Administration). 2007. NOAA 10 year plan for marine aquaculture. National Oceanic and Atmospheric Administration, Silver Springs, MD.

NRC (National Research Council). 1992. Aquaculture in the United States: Constraints and Opportunities. National Academies Press, Washington, DC.

NRC 2010. Ecosystem Concepts for Sustainable Bivalve Mariculture. National Academies Press, Washington, DC.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Annu. Rev. Oceanogr. Mar. Biol.* **16**: 229–311.

PCSGA (Pacific Coast Shellfish Growers Association). 2001. Environmental Policy. Pacific Coast Shellfish Growers Association, Olympia, WA.

PSI (Pacific Shellfish Institute). 2005. North American West Coast Shellfish Industry 2015 Goals: Research and Initiative Priorities. Pacific Shellfish Institute, Olympia, WA.

Rensel, J.E. 1989. Phytoplankton and nutrient studies near salmon net-pens at Squaxin Island, Washington. Technical appendices of the State of Washington's Programmatic Environmental Impact Statement: Fish culture in floating net-pens. Report to Washington Department of Fisheries, Olympia, WA, 312 pp.

Rensel Associates and PTI Environmental Services. 1991. Nutrients and phytoplankton in Puget Sound. Peer reviewed monograph prepared for U.S. Environmental Protection Agency, Region 10, Seattle. EPA Report 910/9-91-002, 130 pp.

Rensel, J.E. and Forster, J.R.M. 2007. Beneficial environmental effects of marine netpen aquaculture. Rensel Associates Aquatic Sciences Technical Report prepared for NOAA Office of Atmospheric and Oceanic Research, 57 pp. http://www.wfga.net/documents/marine_finfish_finalreport.pdf

Ruesink, J.L. and Rowell, K. 2012. Seasonal effects of clams (*Panopea generosa*) on eelgrass (*Zostera marina*) density but not recovery dynamics at an intertidal site. *Aquat. Conserv. Mar. Freshwater Ecosyst.* **22**: 712–720.

SAIC (Science Applications International Corporation). 1986. Recommended interim guidelines for the management of salmon net-pen culture in Puget Sound. Prepared for the Washington Department of Ecology by Science System Applications International, Seattle, WA. 48 pp. https://fortress.wa.gov/ecy/publications/SummaryPages/0087005.html

Soto, D., Aguilar-Manjarrez, J., Brugere, C., Angel, D., Bailey, C., Black, K., Edwards, P., Costa-Pierce, B., Chopin, T., Deudero, S., Freeman, S., Hambrey, J., Hishamunda, N., Knowler, D., Silvert, W., Marba, N., Norambuena, R., Simard, F., Tett, P., Troell, M. and Wainberg, A. 2008. Applying an ecosystem-based approach to aquaculture: Principles, scales and some management measures, pp. 15–35 *in* Building an Ecosystem Based Approach to Aquaculture, Vol. 14 *edited by* D. Soto, J. Aguilar-Manjarrez and H. Hishamunda, FAO, Rome.

Straus, K.M., Crosson, L.M. and Vadopalas, B. 2008. Effects of Geoduck Aquaculture on the Environment: A Synthesis of Current Knowledge. Washington Sea Grant, Seattle, WA, 64 pp.

Tallis, H.M., Ruesink, J.L., Dumbauld, B.R., Hacker, S.D. and Wisehart, L.M. 2009. Oysters and aquaculture practices affect eelgrass density and productivity in a

Pacific Northwest estuary. *J. Shellfish Res*. **28**: 251–261.

Thompson, D.S. 1995. Substrate additive studies for the development of hardshell clam habitat in Washington State: An analysis of effects on recruitment, growth and survival of the Manila clam, *Tapes philippinarum*, and on the species diversity and abundance of existing benthic organisms. *Estuaries* **18**: 91–107.

USDA APHIS (U.S. Department of Agriculture Animal and Plant Health Inspection Service). 2002. Infectious salmon anemia program standards. Veterinary Services, Maine Department of Marine Resources and Maine Aquaculture Association.

WDOE and WDF (Washington Department of Ecology and Washington Department of Fisheries). 1992. Use of the insecticide Carbaryl to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor. Final Supplemental Environmental Impact Statement, 147 pp.

WDF (Washington Department of Fisheries). 1990. Fish culture in floating netpens. Final Programmatic Environmental Impact Statement. WDFW, Olympia, WA.

Wheat, E.E. 2010 Ecosystem engineers: Trophic impacts from tropical headwaters to temperate tideflats. Ph.D. Dissertation, University of Washington, Seattle, WA.

3 Pathogens of Aquatic Animals: Detection, Diagnosis and Risks of Interactions between Wild and Farmed Populations in PICES Member Countries

3.1 Overview

Most PICES member countries have a good understanding of diseases in cultured animals but limited information or research activities related to understanding disease in wild populations. They also have different interests with respect to diseases of concern and host species, and vary widely in their research and diagnostic capacity and magnitude of disease monitoring in both cultured and wild populations. This section provides different member country inputs on various infectious diseases of regional or economic importance in aquaculture in the North Pacific.

3.2 Canada

3.2.1 Pathogens of Importance to Wild and Cultured Aquatic Animals in Canada

The following table lists the major pathogens of importance to the wild and cultured aquatic animals in Canada. For the reportable, immediately notifiable, and annually notifiable diseases, the reporting responsibilities of the public are also given.

Table 3.2.1 Major pathogens of importance to wild and cultured aquatic animals in Canada.

Finfish	Molluscs	Crustaceans
Reportable Diseases (as listed in CFIA Reportable Diseases Regulations)		
Epizootic haematopoietic necrosis **Infectious haematopoietic necrosis*** **Infectious pancreatic necrosis** **Infectious salmon anaemia** **Viral haemorrhagic septicaemia** **Koi herpesvirus disease** **Spring viraemia of carp** **White sturgeon iridoviral disease**	**Disease caused by *Bonamia ostreae*** **Disease caused by *Haplosporidium nelson*** Disease caused by *Marteilia refringens* Disease caused by *Marteiliodes chungmuensis* **Disease caused by *Mikrocytos mackini*** Disease caused by *Perkinsus marinus* Disease caused by *Perkinsus olseni*	Taura syndrome White spot disease Yellow head disease

Table 3.2.1 Continued.

Finfish	Molluscs	Crustaceans
Reportable Diseases (as listed in CFIA Reportable Diseases Regulations)		
Ceratomyxosis (*Ceratomyxa shasta*) Whirling disease (*Myxobolus cerebralis*)		

* Diseases which currently exist in certain areas of Canada are in **bold**.

These diseases are of significant importance to aquatic animal health or to the Canadian economy. Anyone who owns or works with aquatic animals and knows of or suspects a reportable disease is required by law to notify the Canadian Food Inspection Agency (CFIA). If a reportable disease were to be detected, the CFIA would begin an investigation.

Finfish	Molluscs	Crustaceans
Immediately Notifiable Diseases (as listed in Reportable Diseases Regulations)*		
Epizootic ulcerative syndrome (*Aphanomyces invadans*)	Abalone viral mortality (Abalone herpes-like virus)	Crayfish plague (*Aphanomyces astaci*)
Gyrodactylosis (*Gyrodactylus salaris*)	Disease caused by *Bonamia exitiosa*	Infectious hypodermal and haematopoietic necrosis (Infectious hypodermal and haematopoietic necrosis virus)
Oncorhynchus masou virus disease (*Oncorhynchus masou* virus)	Disease caused by *Bonamia roughleyi*	Infectious myonecrosis (Infectious myonecrosis virus)
Red sea bream iridoviral disease (Red sea bream iridovirus)	Brown ring disease (*Vibrio tapetis*)	Necrotizing hepatopancreatitis
	Disease caused by *Marteilia sydneyi*	White tail disease (White tail virus)
	Withering syndrome of abalone (*Xenohaliotis californiensis*)	

* These diseases do not exist in Canada.

If an immediately notifiable disease were to be detected, the CFIA would begin an investigation. Only laboratories are required to contact the CFIA regarding the suspicion or diagnosis of these diseases.

Finfish	Molluscs	Crustaceans
Annually Notifiable Diseases (as listed in Reportable Diseases Regulations)*		
Bacterial kidney disease (*Renibacterium salmoninarum*)	QPX disease (Quahog parasite unknown)	
Enteric red mouth disease (*Yersinia ruckeri*)	Seaside organism (*Haplosporidium costale*)	
Furunculosis (*Aeromonas salmonicida*)		
Streptococcosis (*Streptococcus iniae*)		

* These diseases are present in Canada and are a concern to some of Canada’s trading partners. Only laboratories are required to contact the CFIA regarding the suspicion or diagnosis of these diseases.

Finfish	Molluscs	Crustaceans
Other Diseases of Importance in the Pacific Region.*		
Sea Lice: *Lepeophtheirus salmonis*; *Caligus* spp.		

* These diseases are not listed in the CFIA Reportable Diseases Regulations, but are of a concern with respect to environmental interactions with aquaculture in British Columbia.

3.2.2 Regulations/Rules Regarding Aquatic Animal Health

In 2005, the Government of Canada, supported by its aquaculture stakeholders, invested in the development and establishment of a National Aquatic Animal Health Program (NAAHP). The NAAHP is administered by the Canadian Food Inspection Agency (CFIA) and co-delivered with Fisheries and Oceans Canada (DFO).

The CFIA is the lead federal agency for the NAAHP, getting its authority from the Health of Animals Regulations (HAR) and Ministerial Reportable Disease Regulations under the *Health of Animals Act* (HAA) http://laws-lois.justice.gc.ca/eng/regulations/SOR-91-2/FullText.html). The HAR were amended to include aquatic animals and these amendments became effective on December 22, 2010. Aquatic animal diseases were added to the Reportable Diseases Regulations on January 5, 2011. DFO retains the responsibility for health surveillance of wild aquatic resources, under CFIA Program development.

Prior to these amendments, the health of aquatic animals was the responsibility of DFO, getting its authority from the Fish Health Protection Regulations (FHPR) (see http://www.dfo-mpo.gc.ca/science/enviro/aah-saa/documents/moc-gdp-eng.pdf) under the *Fisheries Act* of Canada (http://laws-lois.justice.gc.ca/eng/ acts/F-14/). These regulations covered only salmonid fishes. The National Code on Introductions and Transfers of Aquatic Organisms provides a mechanism (Introductions and Transfers Committees) for assessing proposals to move aquatic organisms (see http://www.dfo-mpo.gc.ca/science/enviro/ais-eae/code/Code2003-eng.pdf). This code is designed to reduce risks:

1. of harmful alterations to natural aquatic ecosystems;
2. of deleterious genetic changes in indigenous aquatic animal populations;
3. to aquatic animal health from the potential introduction and spread of pathogens and parasites that might accompany aquatic organisms being moved.

At present, Canada is in a transition state between these sets of regulations with components of the NAAHP being phased in over time. At this time the CFIA has assumed authority for the import and export of aquatic animals and domestic disease control in cultured species (and wild stocks where there may be trade implications) for those diseases listed as reportable or immediately notifiable (http://www.inspection.gc.ca/english/anima/aqua/disemala/repe.shtml). Effective December 10, 2011, international imports of any of the aquatic animals listed in Schedule III of the HAR require an import permit issued by the CFIA under the authority of the HAR. The control and issuance of permits for domestic movements of aquatic animals will remain under the Fish Health Protection Regulations and the Fisheries (General) Regulations, following the National Code on Introductions and Transfers of Aquatic Organisms until the CFIA has domestic movement controls in place.

On December 18, 2010, DFO assumed a greater role in the management of aquaculture activities in the province of British Columbia through the Pacific Aquaculture Regulations. As of this date all finfish, shellfish and freshwater aquaculture operations within the province require a federal aquaculture license issued under the *Fisheries Act*, a federal *Navigable Waters Protection Act* permit and a lease from the province of British Columbia in order to continue business. As part of this licensing, all operations are required to develop fish health management plans and to participate in government health audits.

The CFIA has established the biocontainment levels, procedures and protocols that are needed to work safely with animal and zoonotic pathogens. With respect to the importation and research on imported aquatic animal pathogens or infectious materials, the CFIA has recently published the Containment Standards for Facilities Handling Aquatic Animal Pathogens http://www.inspection.gc.ca/english/sci/bio/anima/aqu/aque.shtml. While these standards are mandatory for facilities importing aquatic pathogens, they also provide general guidance on the design and operating requirements for any aquatic animal containment facility.

3.2.3 National and/or Regional Programs Related to the Diagnosis and Control of Diseases of Aquatic Animals

For all of Canada, and for those diseases listed as reportable or immediately notifiable in the Reportable Diseases Regulations, the CFIA is responsible for field operation activities in all instances where animals are under the control or care of individuals (*e.g.*, aquaculture and enhancement operations). The CFIA also leads the investigation when reportable or immediately notifiable diseases are suspected or detected in wild populations.

NAAHP staff perform and coordinate sampling for disease surveillance and monitoring of wild stocks, direct and deliver diagnostic testing, and conduct technology development and targeted research in support of the NAAHP. In British Columbia, veterinarians employed by DFO play various roles in the diagnosis and control of diseases, such as the provision of veterinary services for enhancement facilities and aquatic animal health auditing functions as specified in the Pacific Aquaculture Regulations. In other provinces and territories of Canada, the roles of federal and provincial/territorial departments in aquatic animal health vary.

As part of the NAAHP, a new regulatory diagnostic laboratory system was built from DFO's existing aquatic animal health laboratory infrastructure. The National Aquatic Animal Health Laboratory System (NAAHLS) is comprised of four federal laboratories consisting of the Pacific Biological Station (PBS) located in Nanaimo, British Columbia, the Freshwater Institute (FWI) in Winnipeg, Manitoba, the Gulf Fisheries Centre (GFC) in Moncton, New Brunswick, and the Charlottetown Aquatic Animal Pathogen and Biocontainment Lab (CAAPBL) in Charlottetown, Prince Edward Island. Each of these laboratories has assumed responsibility as reference laboratories for the endemic pathogens that are causative agents of reportable or immediately notifiable diseases. All NAAHLS laboratories are working towards ISO/IEC 17025:2005 accreditation.

In Canada diagnostic and veterinarian services for the aquaculture industry are provided through in-house veterinarians or by private companies. Some universities (*e.g.*, Atlantic Veterinary College) and non-profit laboratories (*e.g.*, BC Center for Aquatic Health Sciences) provide diagnostic services for a fee.

3.2.4 Methods Used for the Identification and Detection of Pathogens of Concern

Finfish diagnostic methods

The FHPR outlines methods for the detection of the following pathogens:

- the viruses causing viral hemorrhagic septicaemia (VHS),
- infectious hematopoietic necrosis (IHN),
- infectious pancreatic necrosis (IPN),
- infectious salmon anemia (ISA),
- the bacterial kidney disease bacterium *Renibacterium salmoninarum*,
- the redmouth bacterium *Yersinia ruckeri*,
- the furunculosis bacterium *Aeromonas salmonicida*,
- the protozoans causing whirling disease (*Myxobous cerebralis*) and ceratomyxosis (*Ceratomyxa shasta*).

Current diagnostic tests approved for regulatory purposes are based on these methods or on the methods outlined in the OIE (World Organisation for Animal Helath).

Finfish viruses

Federal, provincial, private, non-profit, and university laboratories conducting diagnostics for viruses primarily use traditional cell culture based assays followed by confirmation and identification of suspected virus positive samples by molecular analysis (PCR, RT-PCR).

The NAAHP is working towards ISO/IEC 17025:2005 accreditation of cell culture based assays for infectious salmon anemia virus (ISAV), viral hemorrhagic septicaemia virus (VHSV), infectious pancreatic necrosis virus (IPNV), infectious hematopoietic necrosis virus (IHNV), spring viraemia of carp virus (SVCV), and koi herpes virus (KHV). In addition, to facilitate higher throughput testing for viruses during surveillance and monitoring programs, the NAAHLS is developing molecular-based detection methodologies. Specifically, PCR-based diagnostics are being developed or are currently undergoing diagnostic validation to meet OIE standards and ISO (Organization for Standardization) requirements. At present, quantitative reverse-transcription PCR (qRT-PCR) assays are being validated for VHSV, IHNV, IPNV, and ISAV.

Finfish bacteria and parasites

Canadian laboratories are utilizing standard culture, microscopy, and ELISA methods for bacteria and parasite testing. As mentioned above, the FHPR describes in detail methods for testing for a variety of bacterial and parasitic disease agents. Within British Columbia salmonid enhancement facilities, brood fish are annually monitored for the prevalence of bacterial kidney disease (BKD) using ELISA. This screening is used to reduce the use of BKD-positive fish in breeding programs thereby lessening the prevalence of BKD in enhancement facilities.

Within the NAAHP, ISO accreditation is not being sought for bacterial or parasitical diagnostic procedures at the present time. However, molecular techniques have been developed and are being used to identify species of *Gyrodactylus* found on fish in British Columbia waters.

The Centre for Sea Lice Identification was developed to serve as a common taxonomic resource shared among British Columbia sea lice researchers. It is housed at the Centre for Aquatic Health Sciences (CAHS) facility in Campbell River, British Columbia.

Shellfish diagnostic methods

In addition to supporting the NAAHP, shellfish health programs within DFO conduct *ad hoc* mortality investigations, disease screening for introductions and transfers (I&T), and research pertaining to specific diseases of concern in support of both aquaculture and wild shellfish resources. For the Pacific Region, the shellfish health program is located at the Pacific Biological Station (PBS, Nanaimo, British Columbia).

Within the NAAHP laboratory system, ISO-accredited diagnostic procedures for the identification of shellfish diseases that are reportable under the *Health of Animals Act* have been or are under the process of development. Histology is used for routine diagnostics of shellfish disease for both NAAHP and non-NAAHP activities. For some pathogens confirmatory testing is done by molecular testing and/or *in situ* hybridization. The NAAHP is continuing to develop new molecular diagnostic tests for reportable diseases of shellfish and crustaceans. For example, *Mikrocytos mackini* is a microcell parasite of Pacific oysters (*Crassostrea gigas*) found on the west coast of North America. Researchers at PBS are developing and validating to ISO standards a quantitative real-time PCR (qPCR) assay for this parasite. This assay targets the optimal host tissue type and is an improvement over histological detection methods that can sometimes not detect low level infections.

3.2.5 Canadian National Reference Laboratories

Additionally through the NAAHP, national reference laboratories have been established for a number of pathogens (Table 3.2.2).

As the Program progresses, additional pathogens will be added to the list for the three national reference laboratories. The reference laboratories confirm, characterize, and archive all positive detections of the specific pathogen(s). The laboratories also perform technology transfers and proficiency panel testing of diagnostic methods for their designated pathogen(s). The reference laboratories maintain basic and applied research programs on the specific pathogens and contain scientific expertise to facilitate pathogen characterization such as viral genotyping. As indicated above, some reference laboratories also have OIE reference laboratory status for particular pathogens.

Table 3.2.2 List of national reference laboratories in Canada.

Reference laboratory	Pathogen(s)
Pacific Biological Station, Nanaimo, BC	IHNV, VHSV, *Mikrocytos mackini*, Bonamia* spp.*, Marteiliodes chungmuensis*
Freshwater Institute, Winnipeg, MB	IPNV
Gulf Fisheries Centre, Moncton, NB	ISAV, *Haplosporidium nelsoni (MSX), Marteilia refringens, Perkinsus marinus, Perkinsus olseni*

* Indicates OIE reference laboratory status.

BC = British Columbia, MB = Manitoba, NB = New Brunswick

IHNV = infectious hematopoietic necrosis virus, VHSV = viral hemorrhagic septicaemia virus, IPNV = infectious pancreatic necrosis virus, ISAV = infectious salmon anemia virus

3.2.6 Perceived or Realized Risks Associated with the Transfer of Pathogens between Wild and Farmed Hosts

Within the Pacific Region, *i.e.*, British Columbia, there is a great deal of controversy and a highly polarized debate with respect to the real and/or perceived risks of aquaculture to wild salmon. An area of particular interest and debate is the role of aquaculture as a source of pathogens that have negative effects on wild salmon populations. These include the endemic pathogens, IHNV, *Renibacterium salmoninarum* and sea lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) on pink (*Oncorhynchus gorbuscha*) and sockeye (*Oncorhynchus nerka*) salmon.

This controversy has been recently reflected by the inclusion of aquaculture and diseases within the terms of reference for the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (conducted by the British Columbia Supreme Court judge, Bruce Cohen). The Cohen Commission was established in November 2009 by the Government of Canada. Under its terms of reference, the Cohen Commission held hearings to investigate and report on causes of the decline of Fraser River sockeye salmon. As part of its activities, the Cohen Commission engaged scientists to report various aspects that may be related to the decline of Fraser River sockeye salmon. With respect to aquaculture, scientists produced a series of four reports on the topic of impacts of aquaculture on Fraser River sockeye salmon. These reports, which are available on the Commission's website http://www.cohencommission.ca/en/TechnicalReports.php, are as follows:

- Korman, J. 2011. Summary of information for evaluating impacts of salmon farms on survival of Fraser River sockeye salmon. Cohen Commission Tech. Rep. 5A, 65 pp. Vancouver, BC.
- Connors, B. 2011. Examination of relationships between salmon aquaculture and sockeye salmon population dynamics. Cohen Commission Tech. Rep. 5B, 115 pp. Vancouver, BC.
- Noakes, D.J. 2011. Impacts of salmon farms on Fraser River sockeye salmon: results of the Noakes investigation. Cohen Commission Tech. Rep. 5C, 113 pp. Vancouver, BC.
- Dill, L.M. 2011. Impacts of salmon farms on Fraser River sockeye salmon: results of the Dill investigation. Cohen Commission Tech. Rept. 5D, 81 pp. Vancouver, BC.

The main objective of the reports by Korman (2011) and Connors (2011) was to summarize data relevant to addressing aquaculture impacts on sockeye salmon. These data were provided to the Commission by the aquaculture industry, the province of British Columbia and the Government of Canada and included time series and spatial data on:

1. productivity of Fraser River sockeye salmon,
2. biology of Fraser River sockeye (migration routes, *etc*.),
3. oceanographic conditions (physical and biological parameters),
4. the aquaculture industry (farm sites, production levels, mortality rates, *etc*.),
5. pathogens and disease of sockeye and other wild salmonids,
6. pathogens and disease occurrence on salmon farms (sea lice and other pathogens).

Even with the relatively large data sets that were available, Korman (2011) and Conners (2011) were unable to statistically demonstrate any impact of aquaculture activities on Fraser River sockeye salmon.

The technical reports by Drs. Dill and Noakes considered the following factors and their impact on sockeye salmon: (1) Atlantic salmon escapees, (2) effects of farm wastes on benthic and pelagic habitat quality, and (3) disease on salmon farms (sea lice and other diseases). These authors based parts of their analysis on the data and data analysis provided in Korman (2011) and Connors (2011). Noakes (2011) and Dill (2011) were unable to identify any significant effects of aquaculture on Fraser River sockeye salmon.

All of the authors of these technical reports make reference to limitations in the data that were available for their analysis. This is an important point as it clearly demonstrates the requirement for well planned long-term monitoring programs: to assess the health of farmed and wild salmon populations and to collect data on the physical, chemical and biological characteristics of the environment that directly impact the health of salmon, as well as affect the outcome of exposure to infectious agents. Along with monitoring there is also the necessity for research in key areas such as:

1. pathogen transmission rates between farmed and wild fish,
2. pathogen distribution and survival in the environment,

3. the role of environmental factors in the development of disease,
4. the consequences of pathogen exposure at both the individual and population levels under particular environmental conditions.

An example of the type of research needed to support assessments of disease interaction between wild and farmed fish follows. Infection of British Columbia farmed Atlantic salmon with IHNV has resulted in serious disease outbreaks over the periods of 1992–1996 and 2001–2003 (Saksida, 2004; see http://www.agf.gov.bc.ca/ahc/fish_health/IHNV_report_2003.pdf). Recently, Dr. Kyle Garver (DFO, Pacific Biological Station) and collaborators have been examining the potential for IHNV to spread from salmon farms. Laboratory studies have been conducted to determine: (1) the minimum infectious dose of IHNV for Atlantic and Pacific salmon, (2) shedding rates of IHNV from infected Atlantic salmon and (3) survival of IHNV in the environment. These data have been incorporated into physical oceanographic models for the Discovery Island area of British Columbia which allows for the prediction of IHNV spread from sites within this area. Similar physical models have been used to examine the potential for spread of sea lice from farms within the Broughton Archipelago.

3.2.7 Conclusions

There are well developed diagnostic tests for the majority of economically and ecologically important pathogens of salmonids and commercial bivalve species in Canada. As aquaculture in British Columbia is primarily limited to the production of salmonids and bivalve mollusks, this means that there are sufficient diagnostic tests available to meet the needs of disease interactions studies.

The potential for interactions between farmed and wild fish with respect to pathogens and disease remains a major issue of concern in British Columbia. Until recently the focus of this concern was sea lice. However, pathogens such as IHNV are now becoming more of an issue. To date, a very large amount of effort and relatively high level of funding has been applied to this question as it pertains to sea lice. This research has benefited from oceanographers, physiologists, ecologists, and fish health specialists working together to understand this complex question, yet there is still no general agreement as to the magnitude of the effects of sea lice from farmed fish on populations of wild salmonids and *vice versa*.

A general consensus is developing amongst aquatic animal health professionals in British Columbia that in order to understand the potential for such interactions, a broader ecological approach is necessary. This includes understanding how environmental factors directly and indirectly impact the production levels and, in the broadest sense, the health of wild stocks. In addition, it will remain difficult to predict the outcome of such interactions until we have basic information:

1. on long-term trends such as the prevalence and abundance of pathogens in different wild and farmed stocks throughout their lifecycle,
2. for each pathogen, on what conditions trigger the development of disease in different host species and life history stages,
3. for each disease, the mortality rate and the sub-lethal effect(s) of infection for various life history stages and under various environmental conditions, and
4. on how the presence of multiple pathogens affects such interactions.

3.3 Japan

3.3.1 Current State of Fish Diseases in Japan

With the increasing number of aquaculture species in Japan, outbreaks of diseases have increased (Table 3.3.1). Some of the major diseases of the important aquaculture species in Japan are: streptococcosis caused by *Lactococcus garvieae* and nocardiosis of yellowtail (*Seriola quinqueradiata*) and amberjack (*S. dumerili*); Edwardsiellosis of Japanese flounder (*Paralichthys olivaceus*); and iridoviral disease of red sea bream (*Pagrus major*). A long history of aquaculture has resulted in numerous diseases in salmonids; of these, IHN in rainbow trout (*Oncorhynchus mykiss*) and erythrocytic inclusion body syndrome (EIBS) in coho salmon (*Oncorhynchus kisutch*) are the most significant. In ayu (*Plecoglossus altivelis*), bacterial coldwater disease (BCWD) from *Flavobacterium psychrophilum* infection is frequently found. Various diseases of larvae and small juveniles occur in hatcheries; of these, viral nervous necrosis (VNN), caused by the betanodavirus, is a major obstacle in the rearing of many fish species.

Previously, fish disease problems have been limited to aquaculture facilities where fish are reared in intensive conditions. However, in recent years diseases such as koi herpesvirus disease (KHVD) and bacterial coldwater disease (BCWD) have spread and caused damage to wild fish populations.

In recent years, estimated losses of cultured fish from diseases have been halved in Japan (*i.e.*, to around 4–5%) after previously accounting for 10% of total production. Current vaccine usage against streptococcosis caused by *L. garvieae*, which causes major losses in yellowtail aquaculture, has contributed significantly to reducing losses.

3.3.2 National Regulation Framework for Fish Disease Control in Japan

Since 1974, discussions have been held between the Ministry of Agriculture, Forestry and Fisheries (MAFF) and experts in the field on significant non-exotic diseases causing losses each year, and on invasions by exotic diseases having significant potential to affect Japanese aquaculture; the aim is to legislate for control measures to treat the risks. Since the OIE (World Organisation for Animal Health) code of aquatic animal health was adopted in 1995, MAFF accelerated those discussions, and consequently made an amendment to the *Act on the Protection of Fisheries Resources* in 1996 to introduce biosecurity measures against exotic disease invasion. In addition, the *Act on Maintenance of Sustainable Aquaculture Production* was established in 1999, and it prescribes measures to prevent the domestic spread of the listed notifiable diseases.

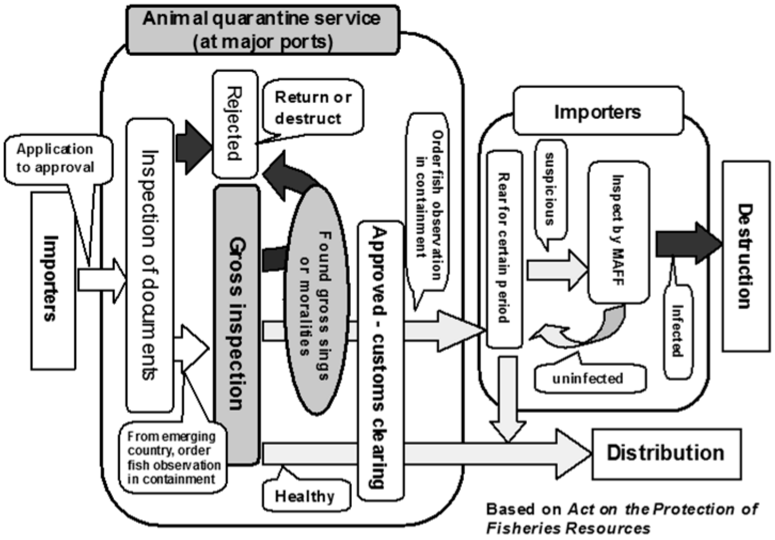
The *Act on the Protection of Fisheries Resources* demands health certification of imported live aquatic animals for the diseases listed in Table 3.3.2. Under the *Act*, the Animal Quarantine Service carries out inspections of imported live animals and can request observation of suspicious animals in a containment facility for a certain period to ensure they are not infected with disease pathogens (Fig. 3.3.1). As shown in Table 3.3.2, the designated diseases for biosecurity on imported salmonid and cyprinid fish, and penaeid shrimp, are almost the same as the OIE-listed diseases for these animals. The diseases designated in the *Act* must be able to be controlled after entry into the country. The controls are based on the general international rule that importing countries should restrict their requirements to those necessary for achieving the appropriate level of national protection, as mentioned in the OIE code.

Table 3.3.1 Major fish diseases in Japan.

Fish	Viral	Bacterial	Fungal	Parasitic
Salmonid	Infectious pancreatic necrosis (IPN) infectious hematopoietic necrosis (IHN) erythrocytic inclusion body syndrome (EIBS) *Oncorhynchus masou* virus (OMV) (SalHV-2)	bacterial kidney disease (BKD) Bacterial gill disease (BGD) Furunculosis Bacterial coldwater disease (BCWD) Vibriosis	Ichthyophonosis Saprolegniasis	Ichtyobodosis
Ayu		BCWD Bacterial hemorrhagic ascites Vibriosis Edwardsiellosis (*E. ictaluri*)	Mycotic granulomatosis	Glugeosis (*G. plecoglossi*)
Carp/goldfish	Viral papillpoma (CyHV-1) Herpesviral hematopoietic necrosis (CyHV-2) Koi herpesvirus disease (KHVD) (CyHV-3) Viral edema	Ulcer disease (Atypical *Aeromonas salmonicida*) Columnaris disease		Muscular myxobolosis (*e.g.*, *M. artus*) Kidney enlargement disease (*Hoferellus carassii*) Dactylogyrosis
Yellowtail	Viral ascites (YTAV) Red sea bream iridoviral disease	Lacticiccicosis (*L. garvieae*) Pseudotuberculosis Nocardiosis (*N. seriolae*) Bacterial hemolytic juandice Streptococcosis (*S. iniae, S. dysgalactiae*)		Muscular kudoosis (*e.g.*, *Kudoa iwatai*) Benedeniasis Neobenedeniasis Heteraxiniasis Blood fluke disease
Red sea bream	Red sea bream iridoviral disease	Edwardsiellosis (*E. tarda*) Gliding bacterial disease (*Tenacibaculum maritimum*)		Bivaginasis
Flounder	viral hemorrhagic septicaemia (VHS) Hirame rhabdoviral disease Viral epidermal hyperplasia	Edwardsiellosis (*E. tarda*) Streptococcosis (*S. iniae, S. parauberis*) Gliding bacterial disease (*Tenacibaculum maritimum*) Bacterial enteritis (*Vibrio ichthyoenteri*) Nocardiosis		Scuticociliatidosis Neoheterobothriasis (*N. hirame*) Neobenedeniasis
Tiger puffer	Snout ulcer disease	Vibriosis Gliding bacterial disease (*Tenactbaculum maritimum*)		Heterobothriasis (*H. okamotoi*) Neobenedeniasis
Other marine fish	viral nervous necrosis (VNN)	Vibriosis		White spot disease (*Cryptocaryon irritans*)
Kuruma shrimp	PAV (= WSD – white spot disease)	Vibriosis	Fusariosis	

Table 3.3.2 Diseases listed in the *Act on the Protection of Fisheries Resources.*

Fish/Crustacean	Disease
Cyprinid fishes	Spring viremia of carp (SVC) Koi herpesvirus disease (KHVD) (**emerging**)
Salmonid fishes	Viral hemorrhagic septicemia (VHS) Epizootic hematopoietic necrosis (EHN) Piscirickettsiosis (*Piscirickettsia salmonis*) Enteric redmouth disease (*Yersinia ruckeri*)
Penaeid shrimps	Tetrahedral baculovirosis (*Baculovirus penaei*) Spherical baculovirosis (*Penaeus monodon*-type) Yellowhead disease Infectious hypodermal and hematopoietic necrosis (IHHN) Taura syndrome



Based on *Act on the Protection of Fisheries Resources*

Fig. 3.3.1 Outline of the biosecurity system for live imported aquatic animals.

The MAFF ministerial ordinance for the *Act on Maintenance of Sustainable Aquaculture Production* specifies that the designated notifiable diseases must meet the following criteria: infectious diseases that have the potential to cause serious production losses and are exotic to Japan or the distribution of the disease is restricted to specified geographic regions. The designated diseases are notifiable to the government, and are the same as those in the *Act on the Protection of Fisheries Resource*s, as shown in Table 3.3.2. When a notifiable disease occurs or a suspicious animal is found, the prefectural governor can order prevention measures to stop further spread including destruction of the affected animals, restrictions on transfers of animals to other locations, and disinfection of the facility and equipment. The cost of the destruction of the animal population is compensated at a certain rate. After the KHVD problem appeared in EU countries, discussions were held on adding the disease to the notifiable disease list. The ministerial ordinance was consequently amended, and KHV disease became a notifiable disease in June 2003, as the disease posed a serious socio-economic threat to the Japanese carp industry.

The National Research Institute of Aquaculture (NRIA) of the Fisheries Research Agency (incorporated administrative agency of Japan) is equipped with a high containment research facility for investigation of exotic diseases. To construct a diagnosis system for each notifiable disease, information is assembled, including photos of the causative pathogens of the affected animal, antisera, and histopathological sections. The actual diagnosis of the disease has to follow the diagnostic guideline of MAFF based on the OIE Manual of Diagnostic Tests for Aquatic Animals. Briefly, a presumptive diagnosis is carried out at a prefectural fisheries research institute (PFRI), and then a confirmative diagnosis is undertaken by NRIA. NRIA reports the final result to the relevant local government and to MAFF. A diagnostic flow chart is shown in Figure 3.3.2 as an example. A guideline handbook and diagnostic technical manuals with photos are provided for practical work; NRIA also provides hands-on training to staff of PFRIs, and test control materials such as PCR (polymerase chain reaction) positive controls. Thus, the diagnostic system for the notifiable diseases is established.

3.3.3 System of Diagnosis and Control of Aquatic Animal Disease Occurrences in Japan

Japan is composed of 47 local prefectural governments. Each local government has its own PFRI. When a disease of a cultured aquatic animal occurs in an aquaculture farm, the farmer usually notifies PFRI of the disease occurrence immediately. The disease is diagnosed by the fish disease experts in the institute, and the farmer is given advice on the treatment of the disease. Furthermore, researchers or “aquacultural extension workers” of the local government visit the local aquaculture farms routinely. They not only give fish farmers the advice to improve culture techniques, but also conduct health surveillances of fish in the farms.

The information of fish diseases is passed to MAFF of the Japanese government by PFRIs through the local governments. OIE-listed diseases, except for notifiable diseases, are also sent to the Japanese government in this manner, and are reported to OIE annually.

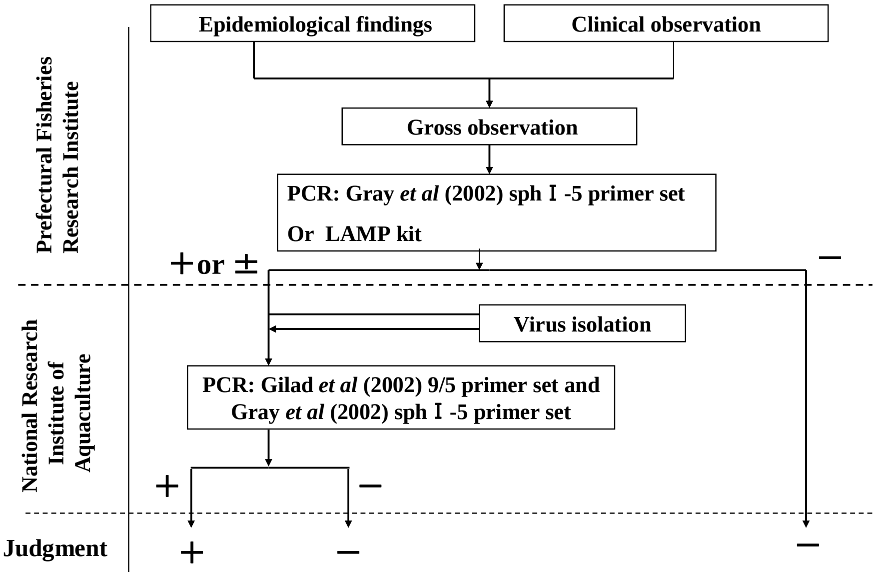


Fig. 3.3.2 Diagnostic flow chart for koi herpesvirus disease.

3.3.4 Establishment and Dissemination of Diagnostic Methods

NRIA accepts requests for disease diagnosis of aquatic animals from public organizations. When a hitherto unknown disease occurs, causing serious problems to fish farmers, PFRIs usually ask NRIA for the diagnosis. Upon request, the disease is promptly studied at NRIA to establish a rapid and accurate diagnostic method for the disease. When the diagnostic method is established, it is transferred to the PFRIs. NRIA often supplies reagents, such as antisera or positive controls needed for the diagnosis. To maintain and improve the technical level of diagnosis for fish diseases, training and education programs are provided for the staff of PFRIs. NRIA provides training classes on such occasions when an important new disease appears or the standardization of the diagnosis method is needed. Japan Fisheries Resource Conservation Association (JFRCA, a governmental incorporated association) provides a systematic training course of fish diseases for the people working for PFRIs. The course program includes various subjects from the laws concerning fish health and disease prevention in Japan, and basic physiology of fish to various disease subjects such as virology, bacteriology, or parasitology. At the end of the course, the trainees are required to take an examination to be qualified as fish disease experts by JFRCA.

NRIA and JFRCA also distribute diagnostic reagents such as antisera or positive controls for PCR to the PFRIs in order to help their work and maintain their level and accuracy of diagnosis. Thus, the diseases of aquatic animals are monitored carefully against their occurrences by PFRIs, with a higher level of diagnostic techniques.

3.3.5 Case Studies of Aquatic Animal Diseases between Wild and Cultured Populations

Flavobacterium psychrophilum, the pathogen of BCWD, could enter into Japan by the importation of coho salmon eyed-eggs from North America. Cultured ayu were infected by this disease in 1987 (Wakabayashi *et al*., 1994). The release of ayu into natural waters to enhance stocks for angling has probably contributed to the domestic spread of the bacterium. Occurrence of the disease has gradually decreased in recent years, probably because of the release of uninfected fish and awareness of prevention measures by anglers. Releasing fry into the river where the parents were caught has been encouraged to maintain genetic variation in the population; this practice might also be helping to control the disease.

KHVD is the only disease now occurring in Japan that is among the notifiable diseases designated under the *Act on Maintenance of Sustainable Aquaculture Production.* A mass mortality of carp caused by KHVD was detected in Lake Kasumigaura in October 2003 (Sano *et al*., 2004). Subsequent retrospective investigations using PCR analysis demonstrated that carp mortality had occurred in another river in May 2003 (Sano *et al*., 2004); because there was no evidence of suspicious mass mortality of carp before this case, it is believed to be the first occurrence of KHVD in Japan. The outbreak of KHVD in Lake Kasumigaura (Takashima *et al.*, 2005) was confirmed in November 2003; therefore, for about one month, a large number of cultured live carp that were not known to be infected had been distributed to other locations, including rivers and lakes used for stocking. Thus, by the end of 2003, KHV had rapidly spread, and infected carp were found in 23 of 47 prefectures in Japan. This serial event, initiated by the infected carp in Lake Kasumigaura, had a severe impact, as demonstrated by the die-off of 100 thousand wild carp in Lake Biwa, the largest lake in Japan; this event had a significant impact on the carp resources of the lake (Matsuoka, 2008). By the end of 2004, KHVD was found in 39 of the 47 prefectures. Almost all of the cases of KHV infection that happened in early 2004 could be linked to the carp that were originally infected in Lake Kasumigaura. The 2004 outbreak of the disease was the highest recorded in the history of KHVD in Japan; subsequently, occurrences have been decreasing each year because of the measures that have been implemented according to the *Act, e.g*., destruction of infected fish, and bans on the transfer of fish to other waters. Aquaculture farms and game fishing facilities, which previously had KHVD, were completely disinfected with chemicals and restocked with uninfected carp; this then resulted in the successful cultivation of fish without reoccurrence of KHVD. In contrast, in natural waters like rivers and lakes, where all of the carp cannot be removed, it may be impossible to eradicate KHV. Therefore, measures are limited to prohibition of the transport of infected carp to other places. Nevertheless, high mortality of carp has not been observed in natural waters that have previously experienced KHV outbreaks.

In kuruma shrimp (*Marsupenaeus japonicus*) aquaculture, penaeid acute viremia (= white spot disease (WSD)) caused by the penaeid rod-shaped DNA virus (= white spot syndrome virus (WSSV)), damaged shrimp production in 1993 in facilities where imported shrimp seedlings were introduced from China (Kimura *et al*., 1996). In the next year, the disease spread to a number of culture ponds in the western part of Japan, and caused severe economic losses to the industry. When the disease first appeared, it was a new, unidentified disease. Serial investigations were carried out on identification of the causative agent, development of a detection method and prevention measures. The causative agent, WSSV, is uncultivable because of a lack of adequate susceptible cells; hence, a PCR-based detection method was developed and became a powerful tool for detection (Nakano *et al.*, 1994). Many PFRIs have installed the equipment, *e.g*., thermal cycler to run the PCR diagnosis of the disease. To prepare uninfected seedlings of the shrimp for aquaculture, prevention measures for hatcheries were developed including virus checking of broodstocks and larvae, disinfection of the water supply and containment rearing. In addition, awareness of the disease by people in charge of both seedling and aquaculture operations has increased, and now prevention measures in aquaculture facilities include the following: disinfection of the bottom sand with chemicals, scarifying and drying the bottom sand in the sun, and use of uninfected seedlings at low rearing densities. In recent years, damage due to WSD in Japan has markedly decreased. For wild populations of aquatic animals, surveillance of some particular diseases, such as WSD of kuruma shrimp, are occasionally made. However, it is difficult to monitor disease outbreaks in aquatic animals in the sea. Hence, the comprehensive understanding of the relationship of diseases between wild and cultured aquatic animals are yet to be achieved, and this is certainly an important subject for future study.

3.3.6 References

Wakabayashi, H., Toyama, T. and Iida, T. 1994. A study on serotyping of *Cytophaga psychrophila* isolated from fishes in Japan. *Fish Pathol.* **29**: 101–104.

Sano, M., Ito, T., Kurita, J., Yanai, T., Watanabe, N., Miwa, S. and Iida, T. 2004. First detection of koi herpesvirus in cultured common carp *Cyprinus carpio* in Japan. *Fish Pathol.* **39**: 165–167.

Takashima, Y., Watanabe, N., Yanai, T. and Nakamura, T. 2005. The status of koi herpesvirus disease outbreaks in Lake Kasumigaura and Kitaura. *Bull. Fish. Res. Agency* **Suppl. 2**: 65–71.

Matsuoka, M. 2008. KHV disease impacts on economics and culture *in* Proceedings of International Symposium on Environmental Change, Pathogens, and Human Linkages, Kyoto, p. 9.

Kimura, T., Yamano, K., Nakano, H., Momoyama, K., Hiraoka, M. and Inouye, K. 1996. Detection of penaeid rod-shaped DNA virus (PRDV) by PCR. *Fish Pathol.* **31**: 93–98 (in Japanese).

Nakano, H., Koube, H., Umezawa, S., Momoyama, K., Hiraoka, M., Inouye, K. and Oseko, N. 1994. Mass mortalities of cultured kuruma shrimp, *Penaeus japonicus*, in Japan in 1993: Epizootiological survey and infection trials. *Fish Pathol.* **29**: 135–139 (in Japanese).

3.4 Republic of Korea

3.4.1 Status of Fish Diseases in Korea

Since a pilot-scale net cage program was first launched to culture marine fish on the south coast of Korea in 1964, the aquaculture industry has expanded rapidly with the help of artificial seed production technology, especially during the 1980s. At the same time, however, mass mortalities of animals in culture have been increasingly reported due to environmental pollution, overstocking of fish and outbreaks of infectious diseases. The main types of aquaculture diseases during the 1990s were a combination of bacterial and parasitic infection, and viral infection alone. This pattern became more obvious in the late 1990s when aquaculture diseases were caused mainly by viral infections alone or by combinations of bacteria with other types of bacteria or parasites. Overall, complicated infections caused by more than two types of pathogen have increased over the years (Fig. 3.4.1).

A diagnostic survey in fish farms with land-based tanks and net cases was conducted on the eastern, western, and southern coasts of Korea and Jeju island during summer from 2000 to 2005. A total of 2,528 marine and freshwater fish samples were diagnosed for infectious diseases. Major infected fish species were olive flounder, black rockfish, sea bream, gray mullet, and rainbow trout, and the main pathogens revealed were Edwardsiellosis, Streptococcosis, Vibriosis, Scuticociliatosis, Iridovirus, Viral hemorrhagic septicemia virus (VHSV) and Viral nervous necrosis virus (VNNV).

Edwardsiellosis is a generalized septicaemia which is often associated with poor water quality and stress in fish. Disease signs may include small cutaneous lesions that can develop into necrotic abscesses, distended abdomen and swollen anus due to the accumulation of ascitic fluid, pigment loss, enlarged kidney, and abscesses on internal organs.

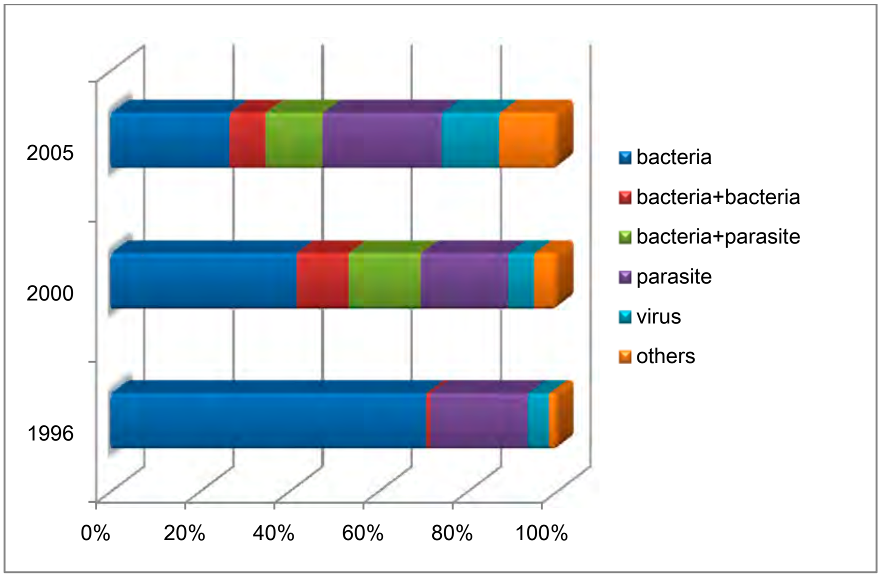


Fig. 3.4.1 Fish disease patterns in Korea.

Streptococcosis has occured frequently in recent years. Beta-hemolytic streptococcus is the causative bacterium which possesses the same biochemical and serological characteristics as streptococci isolated from some marine and freshwater fish, and seems to be related to *Streptococcus iniae.* *S. iniae* and *S. parauberis* are major bacterial pathogens of cultured olive flounder in Korea.

Vibriosis has caused severe economic losses in the fish farming industry worldwide. *Vibrio anguillarum* is a gram-negative, comma-shaped rod bacterium classified to the family Vibrionaceae. It is a halophilic bacterium which causes vibriosis or hemorrhagic septicemia in wild marine fish, cultured-marine fish, freshwater fish, and other aquatic animals in Korea.

Scuticociliatosis invades the skin, fins, muscles, peritoneal cavity, kidney, pancreas and brain of flounder, often leading to death of the host. Heavily infected fish are difficult to treat, in particular when the ciliates enter the brain. In recent years, the number of scuticociliatosis outbreaks has increased explosively in Korea's flounder fry industry. This parasitic disease often results in massive deaths and considerable economic loss.

Iridovirus infection has frequently occurred among cultured fish in Korea. Korean isolates were found to be similar to the Japanese isolate RSIV and one to the Chinese isolate ISKNV; the other Korean isolates were distinct from other foreign iridovirus isolates.

VHSV has caused economically serious damage to the olive flounder farming industry in Korea. Since 2001, VHS has become a common problem in olive flounder farms during low temperature seasons. In 2005, mass mortality of adult flounder occurred on the southern coast of Korea.

In 1998, VNNV was first reported in sevenband grouper in Korea. Since then, high mortality caused by fish nodavirus infection has frequently occurred among marine cultured fish.

3.4.2 System of Diagnosis and Control of Aquatic Animals

There is an urgent need to strengthen quarantines to block the inflow of new overseas diseases due to the rise in international trade of fishery products. The enacted Agreement on the Application of Sanitary and Phytosanitary Measures of the World Trade Organization (WTO/SPS) requires countries to adopt a balance between using sanitary and phytosanitary measures to ensure the health protection of its population while guaranteeing that the measures are not misused for protectionist purposes, and to conduct international duties for OIE-reported diseases, making the disease control infrastructure a critical trade issue.

As a nationally designated aquatic animal quarantine research institute, NFRDI (National Fisheries Research and Development Institute) develops and distributes international/national standard protocols with immunological and molecular biological technology, arranges international standard laboratories and promotes the disease control infrastructure for OIE-reported diseases and data exchange. A diagnostic manual for aquatic animal diseases is shown in Figure 3.4.2.

3.4.3 Fish Vaccine Development in Korea

Infectious diseases such as Edwardsiellosis, Streptococcosis and Iridovirus, pose the biggest single threat to aquaculture in Korea.

Vaccines have become one of the major approaches to combat fish diseases in recent years and have made a major contribution to improvements of fish health in aquaculture. Developing fish vaccines could potentially save aquaculture producers money worldwide by preventing these diseases. Reduction of disease outbreaks has a flow-on effect to decrease antibiotic usage, aiding in the promotion of Korea's "clean green" image. Other advantages include reducing antibiotic use to control these bacteria in culture fish, making a safer, more environmentally friendly consumer product.

There has been much research into the development of effective vaccines, immunostimulants and adjuvants in fish. The introduction of a new generation of both oil- and non-oil adjuvants has greatly improved the efficacy of bacterial vaccines and has resulted in an impressive reduction in mortalities.

The vaccination strategies for the control of viral and bacterial diseases in aquaculture are being studied. For more efficient disease control, NFRDI has been

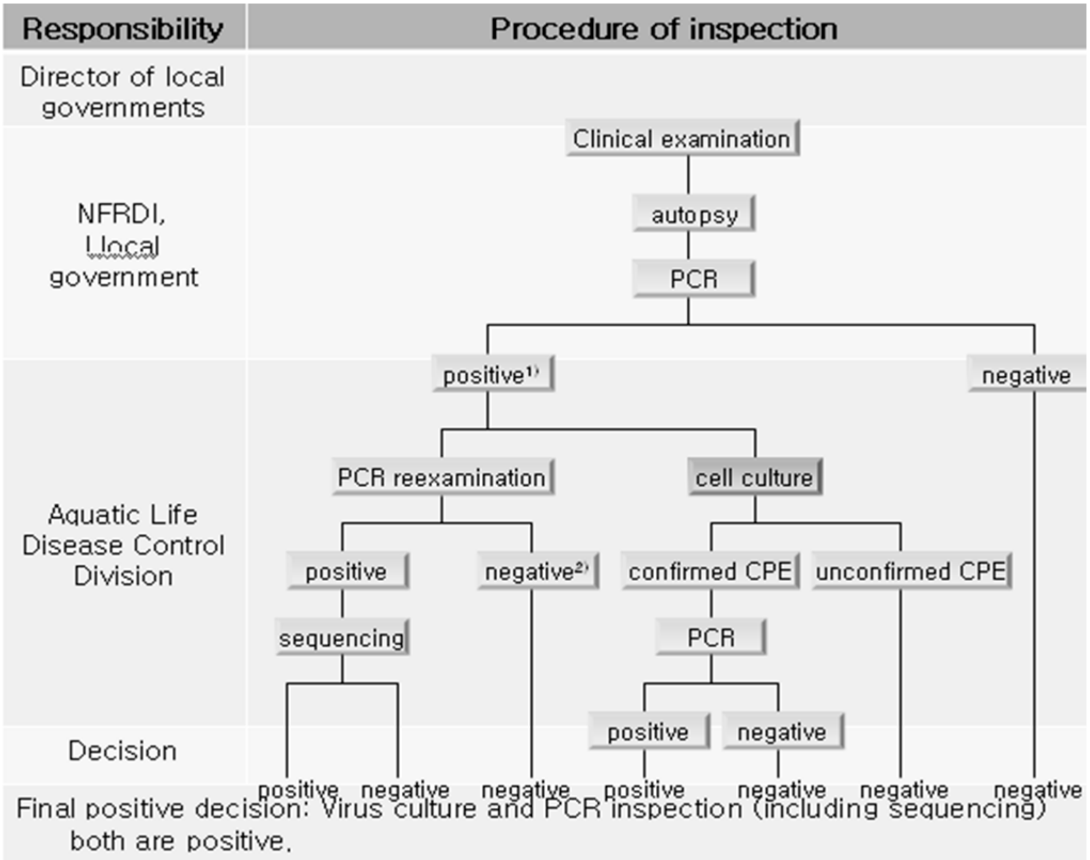


Fig. 3.4.2 Diagnostic manual for aquatic animal diseases produced by NFRDI.

conducting research into the development of fish disease vaccines to convert the existing disease treatment system to a disease prevention system. NFRDI developed a Streptococcosis, Edwardsiellosis, Vibriosis, Streptococcosis-Edwardsiellosis mixed inactivated bacterial vaccine for flounder and recombinant protein vaccine against parrot fish iridovirus in 2005. The disease prevention efficiency rate of a developed vaccine against a target disease was estimated to be 70% since the start of the application.

A vaccine against Nodavirus and a triple mixed vaccine against Streptococcosis *(Streptococcus iniae* and *S. parauberis*) and Edwardsiellosis (*Edwardsiella tarda*) were developed by NFRDI in 2010. These vaccines have been shown to be protective against their respective diseases.

3.4.4 Monitoring of Wild Marine Fish in Korea

Disease surveillance was performed to monitor the prevalence of fish pathogens in wild marine fish caught in coastal offshore waters in 2008. Fish samples were collected from fish markets at landing ports on the eastern, western and southern coasts of the Korean peninsula. Seventeen kinds of fish pathogens were isolated from 152 fish samples. The detection rates of parasites, bacteria or viruses were 21.4, 17.0 and 2.7%, respectively. Some of the detected pathogens and detection rates are shown in Table 3.4.1.

Table 3.4.1 Pathogens and detection rates of wild fish in Korea in 2008 (Cho *et al.*, 2010).

	Pathogen	Detection rate (%)	Host group
Parasite	*Trichodina*	8.2	Brown sole, olive flounder, fine spotted flounder, stone flounder, rock bream, red sea bream, Schegel's black rockfish, black rockfish, spotty belly greenling, red gurnard, panther puffer
	Microcotyle	5.0	Schegel's black rockfish, scorpion fish, sea bass, white croaker, longspine grouper
	Benedenia	1.7	Yellowtail, Schegel's black rockfish, panther puffer
	Caligus	1.7	Yellowtail, Schegel's black rockfish, flathead mullet, panther puffer
Bacteria	*Vibrio*	7.7	Olive flounder, red sea bream, multicolor fin rainbow fish, spotted parrot fish, yellowtail, African pompano, gold striped amberjack, mottled spinefoot, bluefin tuna, Pacific saury, thread-sail filefish, black scraper
	Photobacterium	2.2	Fine spotted flounder, multicolor fin rainbow fish, Schegel's black rockfish, scorpion fish, Pacific herring
	Streptococcus	0.7	Olive flounder
Virus	RSIV	2.0	Fine spotted flounder, thread-sail filefish, black scraper

3.4.5 National Regulation for Control of Aquatic Animal Diseases

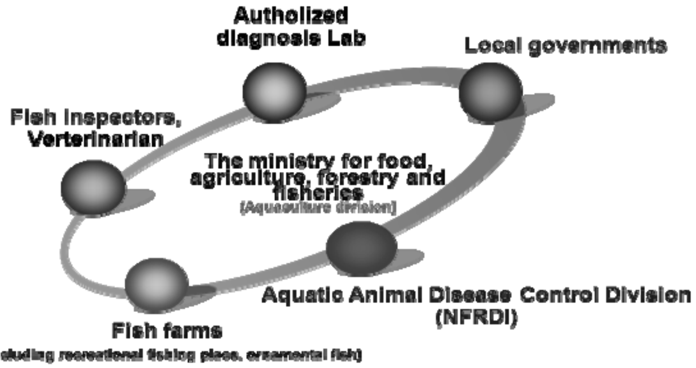
Aquatic Animal Disease Control Act

The *Aquatic Animal Disease Control Act* took effect in December, 2007.

- The aim of the *Act* is to assure the prevention of outbreaks and spread of aquatic animal diseases in Korea.
- The way of prevention of aquatic animal diseases is through notification of aquatic animal diseases, health surveillance, disinfection or destruction, risk analysis and import/export quarantine.
- There are presently 11 kinds of legally-designated diseases in fish, 5 kinds in shellfish and 9 kinds in crustaceans.
- Monitoring, surveillance, movement control or stamping out will be enforced for any disease confirmed by qualified diagnostic laboratories.
- All live aquatic animals (such as fish, molluscs, shrimp) or eggs or gametes have to be declared free from listed diseases for importation into Korea.

The National Fisheries Products Quality Inspection Service is the frontier post for international trade of live aquatic animals that provides quarantine services as well as the preparation of international aquatic animal health certificates.

Constitutions for disease control



Legally-designated infectious disease of aquatic animals

Fish
- Spring viraemia of carp (SVC),
- Koi herpesvirus disease (KHVD),
- Red sea bream iridoviral disease (RSIVD),
- Rock bream iridoviral disease (RBIVD),
- Viral nervous necrosis (VNN),
- Viral haemorrhagic septicaemia (VHS),
- Epizootic ulcerative syndrome (EUS),
- Infectious pancreatic necrosis (IPN),
- Epizootic haematopoietic necrosis (EHN),
- Infectious salmon anaemia (ISA),
- Gyrodactylosis, *Gyrodactylus salaries*.

Shellfish
- Infection with *Bonamia exitiosa* and *B. ostreae*,
- Infection with *Marteilia refringens*,
- Infection with *Perkinsus marinus*,
- Infection with *Xenohaliotis californiensis*,
- Infection with abalone herpes-like virus.

Crustacea
- Yellowhead disease (YHD),
- Taura syndrome (TS),
- White spot disease (WSD),
- Crayfish plague, *Aphanomyces astaci*,
- Spherical baculovirosis, *Penaeus monodon*-type baculovirus,
- Tetrahedral baculovirosis, *Baculovirus penaei*,
- Infectious hypodermal and haematopoietic necrosis,
- Infectious myonecrosis, white tail disease.

Diagnostic laboratories for aquatic animal diseases

Authorized diagnostic labs for aquatic animals include:
- NFRDI (Aquatic Life Disease Control Division),
- Local governments (10 Institutes),
- Universities (2 labs: Pukyung University, Chunnam University).

Diagnostic labs for domestic animals include:
- National Veterinary Research and Quarantine Service,
- Local governments (44),
- Veterinary colleges (10),
- Non-official labs (8).

Roles of aquatic animal disease control institutes

- Development and implementation of a national disease control program for the production/supply of healthy aquatic animals,
- Establishment of a disease control infrastructure to prevent the introduction of overseas aquatic diseases,
- Inspection and management of hazardous fishery products for national health,
- Inspection of infectious diseases of aquatic animals to be released to protect wild aquatic resources and ecosystems,
- Formation of a national integrated disease control network by central and local government organizations,
- Development of disease control technology to minimize disease outbreaks,
- Public service for fishers.

3.4.6 Bibliography

Cho, M.Y., Kim, M.S., Kwon, M.G., Jee, B.Y., Choi, H.S. and Park, M.A. 2007. Epidemiological study of bacterial diseases of cultured olive flounder, *Paralichthys olivaceus* from 2005 to 2006 in Korea. *J. Fish Pathol*. **20**: 61–70.

Cho, M.Y., Kim, M.S., Choi, H.S., Park, G.H., Kim, J.W., Park, M.S. and Park, M.A. 2008. A statistical study on infectious diseases of cultured olive flounder, *Paralichthys olivaceus* in Korea. *J. Fish Pathol*. **21**: 271–278.

Cho, M.Y., Jee, B.Y., Park, G.H., Lee, C.H., Lee, D.C., Kim, J.W., Park, M.S. and Park, M.A. 2010. Monitoring of fish pathogens in wild marine fish of Korean coastal offshore water in 2008. *J. Fish Pathol*. **22**: 75–83.

Choi, H.S., Jee, B.Y., Cho, M.Y. and Park, M.A. 2010. Monitoring of pathogens on the cultured Korean rockfish *Sebastes schlegeli* in the marine cages farms of south sea area from 2006 to 2008. *J. Fish Pathol*. **23**: 27–35.

Choi, H.S., Myoung, J.I., Park, M.A. and Cho, M.Y. 2010. A study on the summer mortality of Korean rockfish *Sebastes schlegeli* in Korea. *J. Fish Pathol.* **22**: 155–162.

Kim, J.W., Jung, S.H., Park, M.A., Do, J.W., Choi, D.L., Jee, B.Y., Cho, M.Y., Kim, M.S., Choi, H.S., Kim, Y.C., Lee, J.S., Lee, C.H., Bang, J.D., Park, M.S. and Seo, J.S. 2006. Monitoring of pathogens in cultured fish of Korea for the summer period from 2000 to 2006. *J. Fish Pathol.* **19**: 207–214.

Kim, M.S., Park, S.H., Cho, M.Y., Kim, J.W. and Park, M.A. 2008. Diagnosis of viral fish disease by polymerase chain reaction-restriction fragment length polymophism. *J. Fish Pathol*. **21**: 181–188.

Kim, M.S., Kim, K.D., Kim, K.W., Park, M.A. and Kim, J.W. 2009. The efficacy and influence on growth of olive flounder *Paralichthys olivaceus* vaccinated against *Edwardsiella tarda* and *Streptococcus iniae*. *J. Fish Pathol.* **22**: 327–334.

Lee, D.C., Cho, M.Y., Cha, S.J., Park, S.H., Park, M.A. and Kim, J.W. 2006. Monitoring of disease in wild marine fish stocks collected in June 2006 by a trawl in the southern Korean waters. *J. Fish Pathol.* **19**: 215–225.

Oh, Y.K., Kim, M.S., Park, M.A., Kim, J.W., Cho, J.Y. and Jeong, H.D. 2010. Serological characteristics and antigenicities of *Vibrio harveyi* isolated from marine cultured fish. *J. Fish Pathol*. **22**: 23–33.

Park, M.A., Lee, D.C., Cho, M.Y., Choi, K.J. and Kim, J.W. 2005. Mass mortality caused by nocardial infection in cultured snakehead, *Channa arga* in Korea. *J. Fish Pathol*. **18**: 157–165.

Park, M.A., Kim, H.Y., Choi, H.J., Jee, B.Y., Cho, M.Y. and Lee, D.C. 2009. Survey of *Trichodina* infection in wild populations of marine fish caught from Namhae region, southern coast of Korea. *J. Fish Pathol.* 22: 163–166.

Seo, J.W., Cho, M.Y., Kim, J.W., Park, G.H. Jee, B.Y., Choi, D.L., Park, M.A. and Oh, M.J. 2010. Aquatic animal health management in stock enhancement. *J. Fish Pathol.* **23**: 85–98.

3.5 Russia

3.5.1 Regulatory Framework for Aquatic Organisms Health in Russia

Russian aquaculture activity is regulated by laws of the Russian Federation. The State standards and requests are issued by several ministries and agencies under the government of Russia (Federal Fishery Agency, Nature Protection Ministry and others). There are several law-making documents regulating the environmental quality and control of habitat alteration for seafood safety. Key examples are:

- "List of maximal permissible concentrations for fisheries ground",
- "Federal sanitary norms and rules".

In these documents the federal norms for control of toxic substances, heavy metals, pathogenic micro-organisms, organic pollutants and others have been established. The monitoring of aquaculture diseases in Russia is carried out by the icthyopathological inspection of the Federal Service for Veterinary and Phytosanitary Supervision under the Ministry of Agriculture.

3.5.2 Aquatic Animal Diseases in Russia

The Russian Federation list of quarantine and especially dangerous fish diseases consists of:

- Viral hemorrhagic septicemia of salmonids (VHS),
- Epizootic pancreatic necrosis of salmonids,
- Epizootic hematopoietic necrosis of salmonids (EHN),
- Epizootic anaemia of salmonids,
- Bacterial kidney disease (BKD),
- Mixobacteriosis,
- Aeromonosis,
- Branchiomycosis,
- Spring viremia of carp (SVC),
- Sphaerosporosis of carp,
- Gyrodactylosis,
- Philometroidosis,
- Bothriocephalosis.

The aquatic animal diseases most abundant in the Russian Federation are shown in Table 3.5.1.

Table 3.5.1 Major aquatic animal diseases in the Russian Federation.

Hydrobiont	Disease (pathogen)			
	Viral	**Bacterial**	**Fungal**	**Parasitic**
Salmonid	Infectious hematopoietic necrosis, Infectious pancreatic necrosis, Viral haemorrhagic septicaemia	Bacterial gill disease, Furunculosis (*Aeromonas salmonicida*), Aeromonosis, Vibriosis (*Listonella anguillarum*)	Saprolegniosis, Branchiomycosis	Ichtyobodosis, Microsporidiosis, Chilodonelles, Cryptocotyles
Ciprinid/ sturgeon	Spring viraemia of carp, Herpesviral disease of *Acipenser baeri*	Citrobacteriosis (*Citribacter freundii*), Mixobacteriosis, Columnaris disease, Polyaetiological bacterial hemorrhagic septicemia	Candidamycosis (*Candida albicans*)	Dactilogyrosis
Invertebrate	Herpes-like virus infection	Bacterial ulceration syndrome, Vibriosis, Staphylococcosis (*Staphylococcus warneri*)	Cladosporiosis, Mycosis (*Sirolpidium zoophthorum, Haliphthorus milfordensis, Ostracoblabe implexa*)	Proctoecosis, Nematopsiosis, Clionosis, Polydoriosis, Petricoliosis, Gastrochaenosis

3.5.3 Conclusion

The health of aquatic organisms in Russia is the subject of public policy. Diseases of aquatic organisms are controlled by the State Veterinary Service. It is constructed on administrative-territorial basis; its branches (departments, laboratories) are found in all major cities, regional and district centers. Veterinary departments provide the leading and coordinating role. Veterinary laboratories diagnose and monitor aquatic organism diseases. Many diseases of aquatic organisms prevalent in the world are considered missing in the country as Russia has a low level of aquaculture development. However, it will be necessary to coordinate the internal standards of Russia with international aquaculture regulations.

3.6 United States of America

3.6.1 Regulatory Framework for Fish Health in the United States

The regulatory framework for aquatic animal health and assessment in the United States is based on State-Federal partnership. The Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture is the co-competent authority for aquatic animal health; the head of APHIS Veterinary Services is the Chief Veterinary Officer for the United States. APHIS shares federal authority with other federal agencies, specifically the U.S. Department of Commerce, National Marine Fisheries Service (NOAA Fisheries), and the U.S. Department of the Interior, Fish and Wildlife Service (FWS), and local authority with the individual States. The State authority for fish health is named independently by each State, but typically resides in the Departments of Agriculture, Fish and Wildlife and/or Marine Resources.

APHIS is granted the authority to govern the prevention, detection, control and eradication of animal diseases under the *Animal Health Protection Act* (http://www.law.cornell.edu/uscode/7/usc_sup_01_7_10_109.html), where animal is defined as any member of the animal kingdom (excluding humans). The *Lacey Act* further specifies that it is unlawful for any person to market, transport or acquire fish or wildlife in violation of any law, treaty or regulation of the United States (http://www.law.cornell.edu/uscode/16/3371.html; http://www.law.cornell.edu/uscode/16/3378.html). State laws and regulations pertaining to aquatic animal health and/or import requirements provide local support (http://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/aquastates.shtml).

Accredited private veterinarians augment State and Federal regulatory authority. More than 80% of all U.S. veterinarians are accredited by APHIS. Activities for accredited veterinarians include issuing export health certificates. These certificates are endorsed by APHIS Veterinary Services (VS) as the competent veterinary authority of aquatic animal health. APHIS-accredited veterinarians may also participate in official surveillance and eradication programs. Private veterinarians seeking accreditation complete training modules to become familiar with APHIS programs and reportable OIE (World Organisation for Animal Health) diseases, as well as regulatory requirements for import and export (http://www.aphis.usda.gov/animal_health/vet_accreditation/), renewed every 3 years. Accredited veterinarians are required by law (Title 9 CFR Chapter 161; http://cfr.regstoday.com/9cfr161.aspx) to immediately notify federal authorities of any confirmed or suspected findings of diseases under U.S. control or eradication programs, or any communicable disease not known to exist in the United States.

In November 2008, APHIS entered into a Memorandum of Understanding (MOU) to coordinate aquatic animal health activities among participating Federal and State agencies. Per this MOU, APHIS is the lead agency responsible for the issuance of export animal health certificates for farm-raised aquatic livestock. NOAA Fisheries is the lead agency responsible for the issuance of export health certificates for marine wildlife or feral aquatic animals. FWS is the lead agency responsible for the issuance of export health certificates for freshwater wildlife and feral aquatic animals. The MOU authorizes NOAA and FWS to request APHIS to issue export health certificates on their behalf. Currently, all live animal export certificates for aquatic animals not intended for human consumption (but which are under the nominal jurisdiction of FWS and NOAA) are endorsed by APHIS per request of NOAA and FWS.

The National Aquatic Animal Health Plan (NAAHP), directed through the Joint Subcommittee on Aquaculture, coordinates responsibilities and activities among the agencies involved in fish health in the United States (http://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/naah_plan.shtml). The NAAHP is not a regulation but provides guiding principles and recommendations to industry, States, tribes and Federal agencies on actions to protect the health of wild and farmed aquatic animals, to minimize the impacts of disease when they occur, and to facilitate the legal movement of aquatic animals and their germplasm in interstate and international commerce.

3.6.2 Laboratory Diagnostics

The USDA's National Veterinary Services Laboratories (NVSL; http://www.aphis.usda.gov/animal_health/lab_info_services/about_nvsl.shtml) act as the reference laboratory for confirmation of aquatic animal diseases new to the United States, or emerging in new regions or species within the United States. Aquatic animal disease testing for routine surveillance, movement testing or disease investigations are conducted at a variety of independent, State and/or Federal laboratories, most typically following American Fisheries Society (AFS) Blue Book or the OIE Manual of Diagnostic Tests for Aquatic Animals (http://www.oie.int/international-standard-setting/aquatic-manual) standards, depending on pathogen and testing purpose. The NVSL approves individual laboratories for diagnostic functions for specific pathogens of federal concern. At present, 22 laboratories are USDA approved to conduct diagnostic testing in support of export health certification of aquaculture species (http://www.aphis.usda.gov/biotechnology/index.shtml). A working group is currently developing requirements for participation in the National Aquatic Animal Pathogen Testing Network (NAAPTN), which include the development of Quality Assessments and Quality Controls for high priority aquatic pathogens of concern. Initial efforts have been focused on viral hemorrhagic septicemia diagnostics.

3.6.3 Current State of Fish Diseases in the United States

The National Animal Health Reporting System (NAHRS) is a cooperative project of the U.S. Animal Health Association (USAHA), the American Association of Veterinary Laboratory Diagnosticians (AAVLD), and the USDA APHIS. State and Federal animal health authorities, industries, and the academic, diagnostic, food safety, and practicing components of the veterinary profession contribute reports of confirmed disease to the system. The NAHRS is designed to gather monthly qualitative information from Chief State Animal Health Officials on the presence of confirmed disease in livestock, poultry and aquaculture species in the United States. Identifying information is not a feature of these reports. In NAHRS reporting a "yes" response from a State indicates that at least one new positive case of disease was confirmed during that specific month. A "no" response indicates that no new positive confirmed cases of disease were noted in the State during that specific month. The NAHRS information is used as a source in preparing the USDA's semi-annual/annual reports to the OIE on the occurrence of animal diseases in the United States. These reports can be accessed on OIE's World Animal Health Information Database (WAHID; www.oie.int/wahid). The NAHRS is one part of a comprehensive and integrated animal health information system that monitors disease status in the United States. Other components include routine or periodic active surveillance initiated through State or Federal efforts, movement testing or routine surveillance *via* producers, and emergency disease control programs. A few examples are provided below.

APHIS VS conducts or coordinates disease control programs and/or surveillance initiatives for aquatic animal diseases as needed (http://www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/). The Infectious Salmon Anemia Program is an example aquatic animal disease control program that highlights State–Federal partnership. In response to the 2001 emergence of Infectious Salmon Anemia (ISA) in Maine, the United States initiated an emergency program for ISA. Participation in the ISA Program, though voluntary at the Federal level, was a requirement for receipt of indemnity funds provided during the initial 2 years, and also an ongoing requirement of site stocking permits granted through the State of Maine Department of Marine Resources (DMR). The ISA Program initiated emergency response activities including a bay-wide depopulation effort in 2002, followed by surveillance, biosecurity and disease control training, evaluation and oversight. Because the epicenter of the ISA outbreaks was centered in a region that extends across the U.S.–Canadian international border, extensive efforts were focused on harmonizing ISA Programs and activities between USDA, Maine DMR and New Brunswick's Department of Aquaculture and Agriculture (DAA) bilaterally. Through the ISA Program, USDA also partnered with NOAA to evaluate the possibility of a marine reservoir of ISAV in free-ranging fish populations (http://www.nefsc.noaa.gov/salmon/factsheets/disease_factsheet.pdf), and with New Brunswick DAA, local veterinarians, the industry, laboratory and research scientists to complete a number of epidemiologic studies to fine-tune control efforts. The last detection of pathogenic ISAV occurred in February 2006. Occasional detections occur of a non-pathogenic genotype which have sequenced as a European HPR0; however, none of these findings have successfully cultured and none are associated with evidence of clinical disease. Surveillance for ISAV in Maine is routine and ongoing. More recently, federal funds have also been appropriated to facilitate surveillance for ISAV in the U.S. Pacific Northwest in response to investigation of possible findings of novel viral genetic material in wild Pacific salmonids in British Columbia. Results of this surveillance to date have been negative for ISAV.

VHS surveillance is another example of national disease control through partnership. VHSV IVa is considered endemic in certain wild marine populations of the North Pacific and periodically detected in returning salmonids associated with hatcheries in neighboring States. However, after notification of the 2005/2006 emergence of a new strain of VHSV (IVb) in wild populations of freshwater fish in the Great Lakes of the United States and Canada, the U.S. implemented an emergency Federal Order restricting movement of susceptible species from the Great Lakes States or Provinces. APHIS VS and the Canadian Food Animal Inspection Agency (CFIA), along with the Great Lakes Fish Health Committee (http://www.glfc.org/boardcomm/fhealth/fhealth.php) designed a U.S.–Canada bilateral surveillance plan to evaluate the distribution of VHSV IVb, and also organized a group of international fish health experts to identify risk factors for disease spread of this newly emerging pathogen. APHIS VS federal funding provided several years of cooperative agreement funding with the States to conduct surveillance, control and education efforts to prevent the spread of VHS outside of the known affected waters or to aquaculture operations. States updated testing requirements for fish movement both within and between State boundaries, and initiated public education campaigns to prevent spread through recreational fishing or boating. The U.S. FWS conducts routine surveillance activities in wild or feral fish in freshwaters, which contribute significantly to the accumulating knowledge base about the distribution of VHSV, as well as other pathogens (http://www.fws.gov/wildfishsurvey/). These collaborative efforts appear successful. To date, VHS IVb has not been found outside the Great Lakes States or in farmed fish settings.

The National Surveillance Unit at APHIS VS Centers for Epidemiology and Animal Health is also available to conduct or consult on the design and/or analysis of non-federally funded State or industry surveillance efforts. Several national assessments of aquatic animal health were completed in 2012. These include:

1. an analysis of VHSV IVb surveillance to support zonation and inter-State trade;
2. assessment of mollusc health in the Pacific, Atlantic and Gulf of Mexico States (including status for *Bonamia exitiosa, B. ostreae, Haplosporidium nelsoni, Marteilia refringens, M. sydneyi, Marteiliodes chungmuensis, Mikrocytos mackini,* ostreid herpesvirus 1 (OsHV-1), *Perkinsus marinus, P. olseni,* and *Vibrio tapetis* pathogens*)*;
3. review of the OIE-list crustacean disease status (white spot, yellow head and taura syndrome) in the Atlantic and Gulf.

Data were analyzed for gaps and inefficiencies and recommendations were made to improve future surveillance. As a result of this State, industry and Federal collaborative effort, the United States was able to establish disease status by region for many OIE notifiable diseases and other diseases of concern. This information will support trade and animal movement decisions and help to safeguard continued population health. Currently, efforts are underway to review available State, Federal and industry surveillance data to support zonation or facility certification for OIE-list and other diseases of concern in freshwater and marine finfish within the United States. A bilateral U.S.–Canada (APHIS-CFIA) aquatic animal surveillance working group is working in parallel to achieve equivalence and efficiency in the approach to disease assessments occurring bilaterally or in shared U.S.–Canada populations or regions.

3.6.4 Disease Interactions between Wild and Farmed Fish

Aquaculture is developing, and will continue to develop at a rapid pace globally. Consequently, disease interactions between farmed and wild aquatic animal populations have been a subject of intense debate for a number of years. Basic tenets of disease ecology (such as mechanisms for disease transmission) confirm the plausibility of disease interactions from farmed to wild fish and wild fish to farmed fish, in either direction. Local transmission can occur, for example, *via* contact or predation of wild fish small enough to pass through cage nets, *via* exchange of water, or perhaps through mutual contact with personnel, gear, vectors, predators, wastes or equipment carrying infectious materials. Disease spread can also occur through spill-over to new species, or *via* movement of live or frozen fish or their products for trade, stock enhancement or routine husbandry practices. Molecular methods able to show genetic lineages may ultimately help to confirm epidemiologic connectivity between wild and farmed fish disease occurrence. In the meantime, proactive discussions might target best methods to foster safe industry and conservation practices and reduce opportunities for disease transmission, in all settings.

Prevention will likely revolve around two central components: biosecurity and surveillance. Biosecurity practices reduce the opportunity for introduction, release or spread of pathogens associated with aquaculture, fisheries, and fish processing activities. However, because populations, whether wild or farmed, are rarely entirely contained to a specific facility or region, basic biosecurity practices on a broader scale are equally, if not more, important. Examples include State and/or Federal import regulations, surveillance and infrastructure for disease investigation, and diagnostics and reporting that help to ensure that the disease status of countries or regions is known and minimally compromised by trade or other animal movement activities. Knowledge of disease status of both source and destination populations can come from a variety of surveillance streams, whether passive or active surveillance, expert knowledge, historic testing, or risk evaluations. Accurate knowledge of disease status supports the health delineation of zones, facilities or populations, and minimizes the risk or impact of business and management decisions. This, in combination with basic biosecurity practices, will help to secure the sustained health of both wild and farmed aquatic animal populations.

4 Summary and Recommendations

This report is a summary of the activities that WG 24 undertook from 2009 to 2012. The Working Group, with the guidance of FIS and MEQ, refined the activities under the terms of reference so that each PICES member country with active Working Group members could contribute to the report. This refinement was required due to the different types of expertise needed to meet the three very different activities outlined in the terms of reference. Additionally, due to external factors, there was a concomitant challenge in attracting current and new members with expertise in marine aquaculture as well as the resources to dedicate to active participation in the new Working Group.

Through topic sessions, workshops and targeted working group activities, different aspects of sustainable marine aquaculture research relevant to WG 24's terms of reference were highlighted. Research activities in all PICES member countries focus on identifying aquaculture–environment interactions, whether to model the impacts or to minimize them through optimizing culture approaches, as well as on research related to disease identification and management.

While there are significant differences in species cultured, culture production method and extent, and the regulatory and management structure in place in the different PICES member countries, the Working Group identified some common issues related to environmental interactions of marine aquaculture. These are as follows:

- Marine finfish culture has a more significant influence on the environment than shellfish or algal culture, primarily due to the addition of feed, which can influence the physical, chemical and biological composition and structure of the seafloor below the culture operations;
- The extent of environmental interactions depends greatly on local physical conditions;
- Near-field, or localized, effects are more substantial than far-field (*i.e.*, hundreds of meters or further) effects;
- Far-field effects are not well characterized or researched;
- Rates of ecosystem recovery depend on local physical conditions, but are generally rapid in environments with high water flow;
- Most PICES member countries are at least examining, if not applying, integrated multi-trophic aquaculture to mitigate and improve interactions;
- Pathogen detection and diagnoses are informed by OIE (World Organisation for Animal Health) standards;
- Development and validation of diagnostic methods and dissemination of those methods are ongoing in most PICES member countries; and
- It is recognized that pathogens can transfer between wild and cultured fish.

Although the original terms of reference requested the Working Group to review and evaluate risk assessment approaches for aquaculture, it was determined that while scientific risk assessment of aquaculture activities are being undertaken in PICES member countries, the organizations that are active within PICES are not always the organizations responsible for undertaking these assessments. Therefore, the second term of reference was modified to focus less on risk assessment *per se*, but instead on providing an overview of the legislative framework for evaluating environmental interactions of aquaculture which integrate, either explicitly or implicitly, aspects of risk assessment. An overview of aquaculture regulatory research was also undertaken in order to provide information on funding sources and institutions that have expertise in aquaculture-environmental interactions research.

Aquaculture remains an important topic for PICES and for the FUTURE program. Based on the experience of WG 24, the Working Group recommends that:

1. Some marine aquaculture issues and analysis can be more holistically addressed through expert groups that include consideration of anthropogenic stressor effects on the marine environment.
2. Any future marine aquaculture-related PICES expert group should be more narrowly focused to not only allow for more directed work, but also to increase the likelihood of experts from all PICES member countries being able to participate and contribute.
3. Active participation from all PICES member countries is key to realizing a complete analysis of sustainable marine aquaculture issues.

Appendix 1

WG 24 Terms of Reference

1. Evaluate approaches currently being used in the different PICES countries to assess and model the interactions of aquaculture operations with surrounding environments. This will involve conducting a comparative assessment of the methodologies, applications, and outputs of different approaches to assess finfish, shellfish, seaweed, and/or integrated multi-trophic aquaculture. Assessments of the approaches will include case studies of their application. As the possibilities for different types of aquaculture and their interactions to be assessed are so vast, it is suggested that a process be developed that prioritize and limits the options. A possible process would:
   a) List types of aquaculture and identify major culture technologies and related species of highest interest to member states. Select three or four important culture technologies and associated species and assess their environmental effects and associated interactions;
   b) Review the scientific literature to ascertain if these possible interactions have been determined to be significant;
   c) Identify methodologies used to predict the effects of these interactions and the history/uncertainty associated with these predictions;
   d) Examine a variety of institutional decision-making models that are used to limit the effects and associated monitoring and mitigation protocols.

2. Review and assess current risk assessment methods used to assess environmental interactions of aquaculture and determine what, if anything, should be changed for application in PICES countries to reflect ecosystem-specific aspects. Following the review and assessment, identify appropriate case studies to compare results among countries in the PICES region. This will be achieved by holding a workshop in the second year to compare and discuss possible standardization of methodologies and the selection of potential case studies for assessment with a standardized approach. Much of the information for this exercise can be derived from "item c" in TOR 1 above. Case studies may then be developed. Responsibilities and functions will be similar to the ICES Working Group on Environmental Interactions of Mariculture (WG-19), so the feasibility of holding a joint meeting with this group will be explored.

3. Assess methods to detect, identify, evaluate and report on infectious disease events and potential interactions between wild and farmed marine animals. If appropriate, develop a recommended standardized approach for detection/evaluation/reporting from wild and cultured populations. The focus of this activity will be on OIE-notifiable diseases and other infectious diseases of regional/economic importance. Discuss and document new and emerging infectious diseases in the PICES region, methods for their detection, and develop models to conduct risk assessments of their potential impacts on both endemic wild and farmed species. If resources are available it would be advisable to test these models by conducting risk assessments on a few (2-3) emerging pathogens. Responsibilities and functions will be similar to the ICES Working Group on Pathology and Diseases of Marine Organisms (WGPDMO), so the possibility of a joint meeting will be explored.

4. As a conclusion to all the above, we propose to hold a PICES session or separate symposium in the third year to present case studies and results, and submit for publication as a PICES document, in appropriate scientific journals, a summary paper that examines development and application of aquaculture-environment interaction models.

Appendix 2

WG 24 Membership

Canada

Edward A. Black
Fisheries and Oceans Canada
200 Kent St.
Ottawa, ON K1A 0E6
Canada
E-mail: blacke@dfo-mpo.gc.ca

Ingrid Burgetz (WG 24 Co-Chairman)
Fisheries and Oceans Canada
200 Kent St., Station 12S013
Ottawa, ON K1A 0E6
Canada
E-mail: ingrid.burgetz@dfo-mpo.gc.ca

Jon Chamberlain
Fisheries and Oceans Canada
Fisheries and Aquaculture Management
Institute of Ocean Sciences
P.O. Box 6000
Sidney, BC V8L 4B2
Canada
E-mail: jon.chamberlain@dfo-mpo.gc.ca

Kyle Garver
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Rd.
Nanaimo, BC V9T 6N7
Canada
E-mail: Kyle.Garver@dfo-mpo.gc.ca

Graham E. Gillespie
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Rd.
Nanaimo, BC V9T 6N7
Canada
E-mail: Graham.Gillespie@dfo-mpo.gc.ca

Stewart Johnson
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Rd.
Nanaimo, BC V9T 6N7
Canada
E-mail: Stewart.Johnson@dfo-mpo.gc.ca

Japan

Katsuyuki Abo (WG 24 Co-Chairman)
Fisheries Research Agency
2-17-5 Maruishi
Hatsukaichi, Hiroshima 739-0452
Japan
E-mail: abo@fra.affrc.go.jp

Toyomitsu Horii
Tohoku National Fisheries Research Institute, FRA
3-27-5 Shinhama-cho
Shiogama, Miyagi 985-0001
Japan
E-mail: thorii@affrc.go.jp

Tamiji Yamamoto
Graduate School of Biosphere Science
Hiroshima University
1-4-4 Kagamiyama
Higashi-Hiroshima, Hiroshima 739-8528
Japan
E-mail: tamyama@hiroshima-u.ac.jp

People's Republic of China

Jie Huang
Yellow Sea Fisheries Research Institute, CAFS
106 Nanjing Rd.
Qingdao, Shandong 266071
People's Republic of China
E-mail: huangjie@ysfri.ac.cn

Qingyin Wang
Yellow Sea Fisheries Research Institute, CAFS
106 Nanjing Rd.
Qingdao, Shandong
People's Republic of China 266071
E-mail: qywang@public.qd.sd.cn

Xuelei Zhang
Center for Marine Ecology Research
First Institute of Oceanography, SOA
6 Xian-Xia Ling Rd., LaoShan District
Qingdao, Shandong 266061
People's Republic of China
E-mail: zhangxl@fio.org.cn

Ping Zhuang
East China Sea Fisheries Research Institute, CAFS
300 Jungong Rd., Yangpu District
Shanghai
People's Republic of China 200090
E-mail: pzhuang@online.sh.cn

Republic of Korea

KwangSik Choi
School of Marine Biomedical Sciences
Jeju National University
66 Jejudaehakno
Jeju 690-756
Republic of Korea
E-mail: skchoi@jejunu.ac.kr

Hyun-Jeong Lim
West Sea Fisheries Research Institute, NFRDI
#14, Seonnyeobawi-ro, Eulwang-dong, Jung-gu
Incheon 400-420
Republic of Korea
E-mail: hjlim@nfrdi.go.kr

Hyun-Taik Oh
Marine Environmental Management Department
National Fisheries R&D Institute, MIFAFF
408-1 Shirang-ri, Gijang-eup, Gijang-gun
Busan 619-902
Republic of Korea
E-mail: ohtek@uga.edu

Myoung-Ae Park
Pathology Division
National Fisheries R&D Institute (NFRDI)
152-1 Haean-ro, Gijang-eup, Gijang-kun
Busan 619-705
Republic of Korea
E-mail: mapark@nfrdi.go.kr

Russia

Galina S. Gavrilova
Pacific Research Institute of Fisheries and
Oceanography (TINRO-Center)
4 Shevchenko Alley
Vladivostok 690950
Russia
E-mail: gavrilova@tinro.ru

Igor Sukhin
Pacific Research Institute of Fisheries and
Oceanography (TINRO-Center)
4 Shevchenko Alley
Vladivostok 690950
Russia
E-mail: suhin@tinro.ru

Dr. Valeria E. Terekhova
Hydrobiology Department
Pacific Research Institute of Fisheries and
Oceanography (TINRO-Center)
4 Shevchenko Alley
Vladivostok 690950
Russia
E-mail: allexxus@yandex.ru

United States of America

Brett Dumbauld (WG 24 Co-Chairman)
Agriculture, Agricultural Research Service (USDA/ARS)
Forage Seed and Cereal Research Unit
2030 SE Marine Science Dr.
Newport, OR 97365
USA
E-mail: brett.dumbauld@ars.usda.gov

Lori Gustafson
U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service (USDA/APHIS)
National Surveillance Unit
2150 Centre Ave.
Fort Collins, CO 80526-8117
USA
E-mail: Lori.L.Gustafson@aphis.usda.gov

J.E. Jack Rensel
Rensel Associates Aquatic Sciences
4209 234th St. NE
Arlington, WA 98223
USA
E-mail: jackrensel@att.net

Jill B. Rolland
U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service (USDA/APHIS)
National Animal Health Programs
4700 River Rd.
Riverdale, MD 20737-1231
USA
E-mail: Jill.B.Rolland@aphis.usda.gov

Appendix 3

WG 24 Annual Reports and Topic Session/Workshop Summaries

PICES Eighteenth Annual Meeting, PICES-2009
October 23–November 1, 2009
Jeju, Republic of Korea

REPORT OF WORKING GROUP 24 ON ENVIRONMENTAL INTERACTIONS OF MARINE AQUACULTURE

The Working Group on *Environmental Interactions of Marine Aquaculture* (hereafter WG 24) held its inaugural meeting from 9:00–12:00 h on October 25, 2009, under the co-chairmanship of Mr. Kevin Amos, Dr. Katsuyuki Obo and Dr. Stewart Johnson (for Ms. Ingrid Burgetz). A list of participants and the meeting's agenda can be found in *WG 24 Endnotes 1* and *2*.

AGENDA ITEM 4
Review of Terms of Reference and reports by activity

Review of Terms of Reference

Dr. Abo provided a brief review of the Terms of Reference (TOR) for WG 24. Working Group members were asked to review them to ensure that they are relevant to all of the PICES member countries. Dr. Glen Jamieson mentioned that the FUTURE Advisory Panel on *Anthropogenic Influences on Coastal Ecosystems* (AICE-AP) will continue to examine and adjust the TOR over time. Dr. Steve Rumrill questioned whether the specific areas outlined in the TOR would be all explored by WG 24 in the future. There was a short discussion on this issue as well as the timing for addressing these specific areas.

Decision: All parties present agreed that the TOR are appropriate for the Working Group at this time. Specific issues to be addressed by the Working Group will be develop before the next Annual Meeting.

Reports of Activity Leaders

Prior to the meeting, PICES member countries were asked to provide information in the following areas as they relate to aquaculture:
1) species of interest and production methods,
2) risk assessment and
3) diseases of aquaculture including potential interactions between wild and farmed marine animals.

The responses received from member countries in response to questions for the three activity areas were reviewed by the Activity Leaders.

Activity 1: Species of interest and production methods (K. Abo)

Dr. Abo received responses from all countries for this activity, which were summarized and presented. During review of these data several areas requiring revision were identified. Dr. Abo will revise his summary to incorporate information provided during the meeting. He will then send this revised version to all Working Group members for a final review and comment.

Action: Dr. Abo will produce a finalized document that will be made available to all Working Group members. This document will provide definition for the various culture methods that are used.

Due to the diversity of species under culture in the various member countries, it was suggested by Dr. Stewart Johnson that the Group consider the use of functional groups rather than individual species. Dr. Jamieson noted that with respect to examining environmental impacts, then this may be a relevant way to proceed. Dr. Brett Dumbauld supported this view.

It was suggested using the information received for Activity 1 that three or four general themes suitable for more detailed study should be identified. Dr. Rumrill suggested that the Group should focus on helping producers understand interactions rather than focusing on differences in production techniques.

Activity 2: Risk Assessment (E. Black)

Dr. Edward Black reviewed the reference terms of relevance to Activity 2 and then provided a brief summary of the responses he received. The TOR were considered in their broadest sense. It was questioned if AICE-AP was most interested in "thresholds of resistance". Dr. Jamieson stated that it was not the only component of risk analysis that the AICE-AP considers important.

Based on his experience, Dr. Black pointed out the long period of time that is required to develop and conduct risk assessments. He suggested that it will be difficult, if not impossible, to meet some of the TOR (especially the TOR #2) within the 3-year time frame of the Working Group. The great amount of information that was received from the member countries is an important first step in the process of risk assessment.

The Group discussed whether TOR #3 could be achieved. It was questioned whether the goal should be to standardize risk assessment methods or to understand the relationships between the different methods used within member countries. If the latter is the case then rewording of the TOR will be required.

There was further discussion on whether the groups should focus on risk assessment for single species, for a specific site or at the ecosystem level. Most responses to the questionnaire focused on studies of single species rather than specific sites or ecosystems.

Mr. Graham Gillespie asked, that since PICES has no official way of providing advice to national governments, whether standardization of risk assessment is a reasonable goal for the Group to try to achieve. He also noted the necessity to standardize terms within the Working Group. He suggested that the Group possibly compile a list of assessment methodologies used in the different countries.

Dr. Gary Wikfors questioned whether standardization of risk assessment methods between countries was possible. He briefly discussed the differences between intercalibration and standardization and suggested that intercalibration of methods should be the way that the Group should proceed. It was suggested that this could be achieved by supplying member countries with a data set that they would analyze using their respective methods/standards. The results of the different analyses then could be compared to understand differences between approaches.

Dr. Galina Gavrilova noted that participation in Activity 2 will be difficult for Russian participants as there is not a lot of aquaculture development or the legislation to support risk assessment activities in Russia.

Decision: WG 24 will not work towards standardization of risk assessment methods. Understanding the different methods used in the member countries and how these methods compare to each other is a more important goal.

Action Items:

- Dr. Black will produce a spreadsheet similar to Activity 1 to summarize the data that were received and circulate it to Working Group members.
- Dr. Black will confirm by email interest of Working Group members in Activity 2.
- Dr. Black will provide a list of risk analysis terms and their definitions to Working Group members, with the ultimate goal of working towards an agreement of which terms to use.
- WG 24 will work towards defining its focus with respect to scale (species, sites or ecosystems).

Activity 3: Report on aquatic animal health (K. Amos)

Mr. Amos reviewed the TOR for Activity 3 and provided a brief summary of the reports received from PICES member countries. In general, most member countries have a good understanding of diseases in cultured animals but limited information or research activities related to the understanding disease in wild populations. He noted that from the U.S. perspective, a major question was whether pathogens shed from aquaculture have negative impacts on wild hosts and the ecosystem. He proposed that the Office International des Épizooties (OIE) guidelines related to aquatic animal health be used as a starting point for the Group. It was questioned whether all member countries subscribed to, or were members of, the OIE. Several group members were unfamiliar with the OIE. However, examination of the OIE website revealed that all member countries are part of the OIE. Dr. Abo noted that participation in the OIE was very important to Japan. He felt that the limited number of responses from Japan was, in part, due to scientists feeling that the information requested for Japan by the Working Group could be accessed through the OIE. Dr. Johnson noted that not all diseases are listed under the OIE and that there may important diseases WG 24 should consider which are not covered.

It was noted that PICES member countries have different interests with respect to diseases of concern and host species. Countries also vary widely in their research and diagnostic capacity, and the magnitude of disease monitoring in both cultured and wild populations. For example, Dr. Gavrilova stated that other than information on parasites of wild fish and bacterial pathogens of sea cucumbers, Russia has limited data on disease. This is in comparison to several other countries which have regional or national programs in Aquatic Animal Health. Dr. Johnson suggested taking a more ecosystem-based approach, possibly focusing on model pathogens for study. Mr. Gillespie suggested that the Group should consider following the earlier suggestion of studying functional groups (*e.g.*, specific types of pathogens such as gram negative bacteria) rather than specific species. There was also a suggestion that the WG 24 needed to better understand bilateral agreements between PICES member countries that are related to the Working Group's mandate. This would help to develop and refine the TOR.

Actions:

- Mr. Amos will forward the URL for the OIE website and confirm with members whether they agree that this is a good starting point for the Group.
- Mr. Amos will send a request to Working Group members to provide information on pathogens of concern that they feel would be suitable for study. These could be of concern for either farmed or wild hosts or both.

Ex-officio membership

Dr. Bychkov provided the group with information on membership within working groups. He noted that many issues facing the Pacific Ocean are not unique to the Pacific and the expertise of importance to PICES activities may be found outside of member countries. He explained *ex-officio* membership on committees and the procedures that need to be followed to bring in *ex-officio* members. As of April 2009 there will be an option to have *ex-officio* members from non-member countries or international organizations. He also mentioned that scientists from member countries can be asked to sit as observers by the working group.

AGENDA ITEM 5
Next Steps

Concern was expressed that there had not been sufficient time set aside for the first meeting of this Working Group. Following discussion of the length of time for the next Working Group meeting, the following was decided upon.

Decision: To request a 1½-day Working Group business meeting to be held in advance of the PICES 2010 Annual Meeting.

WG 24 also discussed the possibility and logistics of a field trip for members after the next Working Group business meeting.

Action: Co-chairs will examine the possibility of a field trip for the Working Group to be held before or after the next WG 24 meeting at PICES-2010. Sources of funding to support a field trip will have to be explored.

AGENDA ITEM 6
Relationship with international organizations

WG 24 discussed possible relationships with ICES working groups. There was also some discussion of a possible of a joint meeting with ICES working groups to be held after the next world aquaculture meeting. Due to the short time frame it was decided that the group would not attempt to develop a joint meeting.

Action: Dr. Black (a member of ICES) will provide information on ICES activities related to Activity 2.

AGENDA ITEM 7
Proposal for a workshop/Topic Session at PICES-2010

The Group discussed the possibility of a workshop and/or session for the next PICES Annual Meeting in Portland, U.S.A., and felt that it was premature to propose a workshop or Topic Session.

AGENDA ITEM 8
Other business

Following a series of discussions the following action items and decisions were agreed upon.

Actions:
- Dr. Johnson will circulate a copy of the minutes of the working group members for comments. Corrected minutes will be circulated to the working group members.
- Mr. Amos will send a reminder to all members responsible for action items within 2 weeks after the end of meeting.
- All members to provide extra information and comments via email to the activity leaders (as soon as possible) but welcome throughout the year.

Decision: WG 24 agreed to support a workshop entitled "*Economic relation between marine aquaculture and wild capture fisheries*" at PICES-2010.

WG 24 Endnote 1

WG 24 participation list

Members

Katsuyuki Abo (Japan, Co-Chairman)
Kevin Amos (U.S.A., Co-Chairman)
Edward Black (Canada)
Brett Dumbauld (U.S.A.)
Galina Gavrilova (Russia)
Graham Gillespie (Canada)
Toyomitsu Horii (Japan)
Stewart Johnson (Canada, representing Co-Chairman, Ingrid Burgetz)
Hyun-Jeong Lim (Korea)
Tamiji Yamamoto (Japan)
Xuelei Zhang (China)

Observers

Alexander Bychkov (PICES)
Ik-Kyo Chung (Korea)
Glen Jamieson (Canada, Chairman MEQ)
Steve Rumrill (U.S.A.)
Mikhail Stepanenko (Russia)
Gary Wikfors (U.S.A.)

WG 24 Endnote 2

WG 24 meeting agenda

1. Welcome by WG 24 Co-Chairs (K. Abo, K. Amos, E. Black and S. Johnson – for Ingrid Burgetz)
2. Introductions by WG 24 members
3. Approval or edits to the agenda
4. Review of terms of reference and reports by activity leaders
   a) Activity 1 – report by Katsuyuki Abo
   b) Activity 2 – report by Edward Black
   c) Activity 3 – report by Kevin Amos
5. Discussion on next steps for each activity
6. Discussion on coordination of potential activities with ICES
7. Proposal for a workshop/Topic Session at PICES-2010 in Portland, Oregon
8. Other work group business
9. Adjourn at 12:00 pm

Afternoon – Field trip to aquaculture facilities hosted by Dr. Hyun-Jeong Lim

PICES Eighteenth Annual Meeting Workshop Summary

MEQ/FIS Workshop (W7)
Interactions between aquaculture and marine eco-systems

Co-Convenors: Katsuyuki Abo (Japan), Kevin Amos (U.S.A.), Galina Gavrilova (Russia) and Hyun Jeong Lim (Korea)

Background

Open-water marine aquaculture has ongoing interactions with its surrounding environment. Some of these interactions have the potential to cause negative and positive effects on the other. For example, pathogens may be transmitted from wild reservoirs to cultured animals and *vice versa*, with the consequence of disease and mortality. Another example is the dispersal of nutrients from a farm site which in some instances negatively impacts the benthos while in other areas may enhance a nutrient-deficient marine zone or contribute to the culture of another aquatic species. Also, changing marine environments, including those impacted by global warming and ocean acidification, have the potential to affect these ecosystem interactions so as to investigate the culture of new farmed species - species that may perform better in altered environments. The PICES Working Group on *Environmental Interactions of Marine Aquaculture* (WG-EIMA; WG 24) has been charged with evaluating existing and potentially new interactions and to develop models that assess the risk of these interactions to include escapes of farmed marine animals (considerations for genetics, competition, and pathogen transfer), discharge of effluent from culture facilities, use of non-native species in culture, and the exchange of pathogens between farmed and wild aquatic animals. Major goals of this workshop included: 1) discussion of tools and models currently used by member countries to assess types of interactions and risks posed by them; 2) developing consensus on aquaculture technologies and indicators of interactions that will be used in completing the terms of reference and preparing the final report of WG-EIMA to include species and methods of culture; and 3) identifying the process by which the work will be carried out under the terms of reference.

List of papers

Oral presentations

Dario Stucchi, Michael Foreman, Ming Guo and Piotr Czajko (Invited)
A coupled biophysical sea lice model for the Broughton Archipelago

Tamiji Yamamoto, Hajime Maeda, Osamu Matsuda and Toshiya Hashimoto (Invited)
Effects of culture density on the growth and fecal production of oyster *Crassostrea gigas*

Xuelei Zhang
Challenges and opportunities of environmental issues faced by coastal aquaculture in China

Galina S. Gavrilova
Some ecological aspects of invertebrate mariculture in semi-closed bights

Jill B. Rolland and Lori L. Gustafson
A model to exclude endemic pathogens from semi-open or open aquaculture facilities: Utilizing compartmentalization to promote epidemiologic separation in shellfish hatcheries

Lori L. Gustafson and Jill B. Rolland
Marine reservoirs for infectious salmon anemia virus in pen-reared Atlantic salmon: Do they play a role in the U.S.?

Kevin H. Amos
A review of infective doses of viral and bacterial pathogens for modeling interactions between marine pen-reared salmon and wild cohorts

J.E. Jack Rensel, Dale A. Kiefer and Frank O'Brien (Invited)
Aquaculture modeling using a GIS-integrated simulation model

Katsuyuki Abo and Toshinori Takashi
Assessing nutrient environments of Nori (*Porphyra*) aquaculture area by using numerical model

Brett R. Dumbauld and Jennifer L. Ruesink
Evaluating the effects of bivalve shellfish aquaculture and its ecological role in the estuarine environment in the United States

Edward A. Black
Aquaculture risk assessments and ecosystem-based management

Motoyuki Hara and Toyomitsu Horii
Evaluation of the impacts of seedlings on abalone reproduction by genetic approach

Qtae Jo, Su-Kyoung Kim, Chae Sung Lee, Jin Yeong Kim and Victor D. Dzizyurov
Production of healthier *Patinopecten yessoensis* seeds for aquaculture on the Korean and Russian coasts of the East Sea

Posters

Larissa A. Gayko
The long-term physical-statistical method for the forecast of mollusks' yield at marine farms in Primorye (Sea of Japan)

Larissa A. Gayko
Interrelation between hydrometeorological and biological parameters of marine farms in Primorye (Sea of Japan)

Arthur A. Kos'yanenko
The distribution of commercially important species of sea squirts (Ascidians) in Alekseeva Bay of Peter the Great Bay

Liping Jiao, Gene J. Zheng, Tu Binh Minh, Liqi Chen and Paul K.S. Lam
Persistent toxic substances in remote lake and coastal sediments from Svalbard, Norwegian Arctic: Levels, sources and fluxes

Valeria E. Terekhova
Effect of the prophylactic antibacterial treatment on the intestinal microflora of cultivated sea cucumber, *Apostichopus japonicus*

Gary H. Wikfors
Flow-cytometric applications for bivalve hemocytes: Tools for assessing mollusc/ecosystem interactions

April N. Croxton, Gary H. Wikfors and Richard D. Gragg, III
An evaluation of hemocyte profiles from oyster populations located in two Florida bays

PICES Nineteenth Annual Meeting, PICES-2010
October 22–31, 2010
Portland, U.S.A.

REPORT OF WORKING GROUP 24 ON *ENVIRONMENTAL INTERACTIONS OF MARINE AQUACULTURE*

The Working Group on *Environmental Interactions of Marine Aquaculture* (hereafter WG 24) held its second meeting on October 24, 2010 in Portland Oregon, under Co-Chairmen Dr. Katsuyuki Abo (Japan), Dr. Brett Dumbauld (U.S.A.), and Ms. Ingrid Burgetz (Canada). The list of participants and the meeting's agenda can be found in *WG-24 Endnotes 1* and *2*.

AGENDA ITEM 1
Welcome and introductions

Ms. Ingrid Burgetz provided welcome remarks which were followed by round table introductions. WG 24 members from Canada, Japan, Korea, Russia, the United States and were present. Observers from Canada, China, and Russia and also participated in the meeting. The agenda was reviewed; no comments or modifications were made.

The ability of WG 24 to re-define priorities within the overall Working Group (WG) Terms of Reference (TOR), and linking the activities to broader PICES activities was discussed. It was noted that the WG can select priorities based on interest and expertise of the members, and that these priorities would then be presented to the two parent Committees (MEQ and FIS) for approval. As this is the last year of WG 24's mandate, it was emphasized that the WG needs to demonstrate how marine aquaculture fits within PICES and the FUTURE program. Dr. Toyomitsu Horii (Japan) reported that he had attended the inter-sessional FUTURE workshop in Seoul, Korea (August 16–18, 2010) on behalf of the WG. There is a good fit for WG 24 within the FUTURE program, particularly in areas such as management of coastal resources and climate change.

AGENDA ITEM 2
Review of TOR activities from 2009-2010 and proposals for action items for 2010

Discussion of list of marine aquaculture–environment interactions

Through the circulation of documents via e-mail over the past few months, the WG 24 has agreed on categorizing the types of marine aquaculture and environment interactions. The WG discussed this categorization and as a result of this discussion the following modified list of interactions (separation of release of nutrients, non-cultured organisms and organic materials) are:

- Pest and pathogen interactions/management
- Benthic habitat interactions/alterations
- Chemical release
- Genetic interactions
- Alteration in nutrients/harmful algal blooms/eutrophication
- Release of non-cultured organisms
- Release of organic materials
- Effect of noise
- Alteration in light
- Marine mammal/bird interactions

Dr. Jack Rensel (U.S.A.) suggested that WG 24 broaden environmental interactions to include harmful algal blooms and eutrophication. He also noted that alteration in nutrients covers both water column and benthic impacts although it usually implies water column. He stressed that an important contribution of the WG is the opportunity to compare and contrast approaches used in different member countries.

As part of the process in developing the categories of marine aquaculture-environment interactions, WG members were requested to identify the most important interactions for their country. Importance was defined as from an environmental, societal and/or economic perspective. Participants at the WG meeting were asked to confirm and/or comment on their responses. The following table identifies which interactions, by country, were identified as being most important.

Canada	Wild/cultured species interactions: ▪ Disease interactions ▪ Pest management
China	▪ Disease interactions: bidirectionality of disease transfer; diseases impacting shrimp production are of particular importance. ▪ Genetic interactions
Japan	▪ Pest and pathogen management ▪ Benthic interactions/ ▪ Alteration in nutrients
Korea	▪ Pest and pathogen interactions ▪ Genetic interactions ▪ Benthic habitat interactions ▪ Alteration in nutrients
Russia	Wild/cultured species interactions: ▪ Alteration of nutrients/pollution ▪ Disease interactions
USA	▪ Pest and pathogen interactions ▪ Benthic habitat interactions ▪ Alteration in nutrients

Action Item: Ms. Burgetz will revise the list based on discussions (revised above) and will re-circulate the list to WG 24 members.

Discussion of Term of Reference 2: Risk assessment

TOR-2 Country reports

Ms. Ingrid Burgetz and Dr. Jay Parsons (Canada) provided a brief update on the upcoming change in responsibility for the regulation of aquaculture in British Columbia, Canada. The federal government, through the Department of Fisheries and Oceans will be assuming responsibility for regulating aquaculture with the exception of issuing licenses for siting of new aquaculture operations, which will still be the responsibility of the Province of British Columbia.

Dr. Galina Gavrilova (Russia) provided a brief country report indicating that the concept of risk and of risk assessment is not as popular in Russia as it is in Canada or the U.S.A. Russia is not a member of the World Trade Organization, and aquaculture activities are regulated by laws of the Russian Federation. The State standards and requests are issued by several ministries and agencies under the government of Russia (Federation Federal Fishery Agency, Ministry of Nature Protection and others). There are several law-making documents that regulate environmental quality and habitat alteration control for safety of seafood. The primary documents are: (1) List of maximal permissible concentrations for fisheries grounds; and (2) Federal sanitary norms and rules. In these documents the federal norms for toxic substances, heavy metals, organic pollutants and others have been established.

Dr. Brett Dumbauld (U.S.A.) provided information on recent changes in US shellfish aquaculture regulations. The US Army Corps of Engineers is responsible for permitting shellfish aquaculture and recently issued a new nation-wide permit with regional administration and review. The new regulations are being phased in, and the nationwide permit covers existing aquaculture activities but does not cover new ones. Approaches at the regional and state levels are still being worked out. Some activities and species are regulated only under the national permit, while others will require additional information and different approaches, and there may be additional regulations at the state-level. From the aquaculture industry perspective, these differences in regulations may pose problems.

Dr. Jack Rensel provided an update on the expansion of fish farming in the State of Washington, which is expanding on Indian tribal lands along the Columbia River. Specifically, the Colville Tribe, a self- governed tribe, has control and oversight of aquaculture activities rather than the State of Washington or the US Environmental Protection Agency. Dr. Rensel is working to make sure the expansion is done with an eye to carrying capacity. There is also expansion of aquaculture in the Juan de Fuca Strait, with large companies focusing on black cod and salmon.

No other country comments were received.

Ms. Ingrid Burgetz noted that each country takes a different approach to addressing the question of risks associated with aquaculture. In preparation for the WG 24 meeting at PICES-2009 in Jeju, Korea, members were asked to identify the mechanisms and methods currently being used to assess environmental interactions of aquaculture. The report, re-circulated prior to the WG meeting at PICES-2010, was proposed to form the basis of the WG's activities under TOR-2. The report is currently unfinished, and in need of revising by various member countries, due in part to some legislative changes. It was noted that the original response from Korea was mistakenly omitted from the report circulated, and that Russia's country report contains additional details to be included in this report.

It was proposed that the report from Japan could be used as a template for revising country responses. Specifically, members will be asked to identify the legislative framework for aquaculture in their country, and the current status of research on environmental assessment of aquaculture.

Action:

- WG Co-Chairmen will re-send the report with the suggestion to members to consider using the same approach as Japan for answering the original question.
- Each member will review their contribution to the TOR-2 report from 2009 and provide updates and revisions, as required, by **December 15, 2010**.

(Originally the agreed on date was November 30, 2010; however, the Co-Chairmen have agreed that a minimum of 30 days is appropriate for WG members to be able to gather and submit the additional details).

Note: This report, once finalized, will be WG 24's final activity under TOR-2.

Discussion of Term of Reference 3: Disease interactions

Dr. Dumbauld introduced the term of reference for Activity 3, and provided a brief overview of the status of the 2009 report on TOR-3, and options for activities under TOR-3. An example was whether the WG wants to look at new methods for disease diagnostics.

WG 24 briefly discussed whether the 2009 report should be further refined, and what purpose a revised report would serve. Dr. Lori Gustafson (U.S.A.) has agreed to take the lead role in coordinating a more comprehensive report on disease interactions and suggested that one way of dividing up the TOR-3 would be to focus on the following different components:

1. describe current strategies re: surveillance, diagnostics and reporting;
2. describe methods to detect interactions (transmission between wild and farmed), including bringing together some information on what is going on in each member country;
3. describe emerging diseases of concern;
4. model the risks of emerging diseases – developing an approach to predicting the probability of disease occurring.

Realistically, WG 24 is unlikely to be able to address each of these components, and it was suggested that the WG not focus on detection and modeling of risks of interactions. The WG agreed in principle that the output should include an overview of diseases of aquaculture in the North Pacific, with different country inputs and provide an overall picture of where the disease research community as a whole might focus. This report should be targeted as a review for publication in a peer-reviewed journal. In addition to the existing WG members, a discussion on how to further engage experts in each of the member countries took place as additional expertise was agreed to be important to allow for a more comprehensive review.

TOR-3 Country Reports

Dr. Kong Jie (China, observer) provided an update on the on-farm use of diagnostic kits for viruses of aquaculture concern (*i.e.*, white spot in shrimp culture), stating that although there are now 8 to 10 viruses that can be diagnosed with these kits that have been under development in China for a number of years, farmers do not like to use the kits as they do not assist in addressing the disease, only identifying it.

Dr. Gavrilova noted that diseases of aquaculture animals are a great problem in Russia, as in other countries. In Russia, there are Handbooks for the regulation of aquaculture operations in fresh water. However, until recently a special control agency for marine aquaculture products did not exist. Disease monitoring of marine aquaculture products is conducted only by research institutes. These results are then presented to the Federal Fishery Agency. The first results of research investigations in experimental hatcheries were presented in Russia’s country 2009 report.

Dr. Myoung Ae Park (Korea) noted that the focus in Korea is diagnostics: surveys on fish farms and discussions with fish farmers about diagnostic methods and treatment options such as the use of vaccines, *etc*. Work is also focusing on prevention, through the development of vaccines (including viral and bacterial disease vaccines) and chemical approaches. OIE listed diseases are important.

Dr. Abo provided a brief introduction of the Japanese situation. Japanese members of the WG will provide information on diseases, diagnostics and vaccines.

Dr. Stewart Johnson (Canada) provided an overview of aquaculture-related disease and health research and scientific efforts in Canada, which are a combined effort between government, universities, First Nations and diagnostic laboratories. Diseases and pests of concern include sea lice, IHNV, *Renibacterium*, and *Aeromonas*. He noted the importance of understanding both the host biology and reaction and the information about pathogens of concern – where they occur, their natural prevalence in wild populations, survival outside of hosts, *etc*. He then provided a more detailed overview of the types of research that are being undertaken on sea lice and IHNV as examples, as well as research on developing new tools to assess the health of mussels and littleneck clams.

Action:

- WG members who work on disease will meet on October 25, 2010 to develop a draft Table of Contents for TOR-3 and to discuss how to move forward on this activity. The developed draft Table of Contents can be found in *WG-24 Endnote 3*.
- A report, designed for submission to a peer-reviewed journal, will be developed, using the Table of Contents with draft country reports due to Dr. Lori Gustafson on **April 1, 2010.**

Country leads for this activity are: Stewart Johnson (Canada); Valeriya Terekhova (Russia); Myoung Ae Park (Korea); Katsuyuki Abo (Japan); Lori Gustafson (U.S.A.).
Note: No country lead has been identified for China.

Discussion of Term of Reference 1: Modeling interactions

Dr. Abo provided an overview of TOR-1. He reviewed the 2009 report, including a summary of the types of culture methodologies used in each member country. At the PICES-2009 it was decided that WG 24 would use functional groups rather than individual species. The table was modified to summarize by functional groups (*i.e.*, netpen carnivorous fish, long line/raft filter feeders, sowing culture filter feeders, detritus feeders).

Similar to the activities that will be undertaken for TOR-3, a proposal had been sent to WG 24 members so that the WG could build on presentations given at the PICES-2008 and -2009 mariculture sessions that focused on benthic interactions. This proposal was discussed at length, and the consensus was that benthic interactions are too narrow for a focus. The WG agreed that the focus for a literature review and analysis under TOR-1 will be on:

> Short- and long-term effects on the near and far-field benthic environment, including physical and chemical changes and rates of recovery. This will include beneficial as well as negative effects.

It was determined that by focusing efforts on near and far-field interactions, this would be sufficiently comprehensive for all member countries to contribute to the review. Additionally, it was noted that the review should include an analysis of algal culture, which has both positive and negative effects in the near and far-field. Dr. Jie described new work to look at integrated aquaculture to consider the economics as well as ecological factors. He thought that chemical and other factors are likely being considered in this research.

Action:

- WG members interested in TOR-1 will meet on October 25, 2010 to develop the Table of Contents (see *WG-24 Endnote* 4) for a report addressing the focal statement, and to finalize a plan to move this activity forwards.
- The report on near and far-field interactions will be developed by WG members identified as leads (see below), using the Table of Contents (see *WG-24 Endnote 4*) with draft country reports to be submitted to Dr. Abo on **April 1, 2010.**

Country leads for this activity are: Ingrid Burgetz (Canada); Galina Gavrilova (Russia); Hung Jeong Lim (Korea); Katsuyuki Abo (Japan); Brett Dumbauld (U.S.A.).

Note: No country lead has been identified for China.

AGENDA ITEM 3
Proposal for a Topic Session at PICES-2011

A proposal for a scientific Topic Session at the upcoming PICES meeting in Khabarovsk, Russia in 2011 was developed (*WG 24 Endnote 5*). Through discussions, WG 24 decided that the inclusion of socio-economic considerations related to marine aquaculture and environment interactions would be valuable and aligns with the FUTURE program. The WG requested a full day for the session, and support for 2 invited speakers.

WG 24 discussed the possibility of using the Topic Session as the basis for putting together a special publication in the new journal *Aquaculture Environment Interactions*. It was decided that should the proposal for a Topic Session be accepted, then the WG would again initiate this discussion, as it would help to inform who should be approached as invited speakers as well as other researchers whose presentations and input would be valuable to the session. Drs. Gavrilova, Dumbauld, and Abo agreed to be co-convenors and lead this activity.

AGENDA ITEM 4
Review of action items and deliverables for 2010–2011

Ms. Burgetz reviewed the action items and deliverables for 2010–2011 and emphasized that this was the last year of WG 24 under the current mandate, and that it is very important that the WG produce the agreed-on reports under all three TOR. She emphasized the need to stick to the April 1, 2011 deadline for submitting country reports because the activity leads and WG Co-Chairmen will then require time to analyze the reports and write the report's introduction and the analysis and discussion sections. The report will then be circulated to the WG members at the end of August 2011 for their review and comments in September and October 2011, prior to the WG meeting at PICES-2011.

In addition to developing and finalizing the reports on each TOR, over the next year WG 24 will need to consider what recommendations they would like to put forward to the two parent Committees, MEQ and FIS, for future mariculture-related activities for PICES, including Topic Sessions, requesting that the TOR of WG 24 be re-evaluated and extended, or proposing TOR for a new working group.

The WG meeting at PICES-2011 will need to focus on finalizing the reports, consider any proposals for mariculture-related topic sessions or workshops for PICES-2012 and discuss and finalize any recommendations for future PICES work on mariculture that can be proposed to the MEQ and FIS committees.

WG-24 Endnote 1
WG-24 participation list

Members	Observers
Katsuyuki Abo (Japan, Co-Chairman)	Kong Jie (China)
Ingrid Burgetz (Canada, Co-Chairman)	Jay Parsons (Canada)
Brett Dumbauld (U.S.A., Co-Chairman)	Olga Lukyanova (Russia)
Galina Gavrilova (Russia)	Steven Rumrill (U.S.A.)
Graham Gillespie (Canada)	Darlene Smith (Canada)
Lori Gustafson (U.S.A.)	
Toyomitsu Horii (Japan)	
Stewart Johnson (Canada)	
Hyun-Jeong Lim (Korea)	
Myoung Ae Park (Korea)	
Jack Rensel (U.S.A.)	
Tamiji Yamamoto (Japan)	

WG-24 Endnote 2
WG-24 meeting agenda

1. Welcome and introductions
2. Overview of TOR activities from 2009–2010 and proposals for action items for 2010
   - List of interactions
   - TOR-2: Finalizing 2009 report and country updates
   - TOR-3: 2009 report, country updates and 2010 activities
   - TOR-1: 2009 report, country updates and 2010 activities

3. Proposal for a Topic Session or Workshop at PICES-2011

4. Review of action items and deliverables for 2010–2011
   - Reports
   - Topic Session proposal
   - Proposal for future marine aquaculture work in PICES

WG-24 Endnote 3

Pathogens of aquatic animals: Detection, diagnosis and risks of interactions between wild and farmed populations in PICES member countries

1. Executive Summary

2. Introduction

3. Status Review by Country

Each country will submit a document reviewing some or all of the following topics. If possible countries will identify key concerns, critical information sources and primary organizations and/or regulations directing aquatic animal health. However, it is not expected that these reviews will be exhaustive. Rather, countries may choose to highlight select diseases, diagnostics or epidemiologic methods of regional importance and/or provide a foundation or direction for future research.

3.1 Topics

3.1.1 Pathogens of importance to wild and cultured aquatic animals by country

- May include information on invertebrates and/or finfish
- May include diseases of importance as defined by the OIE, as well as diseases of regional or country significance.
- May consider economic and/or ecological significance.

3.1.2 Overview of the regulations/rules regarding aquatic animal health

- Identification of departments or agencies involved in the regulation and/or control of aquatic animal diseases
- Brief review of the regulatory environment

3.1.3 Overview of national and/or regional programs related to the diagnosis and control of diseases of aquatic animals

- Identification of laboratories/departments etc. that are actively involved in disease diagnostics and/or research related to diagnostic test development

3.1.4 Overview of the methods used for the identification and detection of pathogens of concern

- To include diagnostic tests approved for regulatory use as well as those that are used within the research community.

3.1.5 Overview of perceived or realized risks associated with the transfer of pathogens between wild and farmed hosts

- This may include the introduction of pathogens resulting from the translocation or natural migration of animals from aquaculture or wild populations.
- This could include statistical methods, research activities or disease spread models used to study the potential transfer of pathogens.
- This could include examples or case studies of presumed disease transmission between aquaculture and wild populations.
- This could also include steps taken to reduce risk of transmission between aquaculture and wild populations.

4. Conclusion

The conclusion will summarize progress and gaps in the study of pathogen transfer between aquaculture and wild aquatic animal populations. Suggestions may include future conference sessions, new working group objectives, or peer-reviewed publications considering the need for harmonization or further development of research and surveillance methods.

WG 24 Endnote 4

Assessing environmental interactions of marine aquaculture: A review of long- and short-term, near- and far-field effects of marine aquaculture on benthic communities, including chemical and physical changes, and rates of ecosystem recovery in PICES member countries

1. **Executive Summary**
2. **Introduction**
3. **Status Review by Country**

   Each country will submit a document reviewing some or all of the following topics. It is not expected that these reviews will be exhaustive. Rather, countries may choose to highlight select research results and projects of regional importance and/or provide a foundation or direction for future research. A generalized overview/analysis may be provided to introduce the detailed information, below.

   3.1 Finfish Aquaculture Review
   - **3.1.1** Near-field effects (including short and long term, resiliency of ecosystem to perturbation)
     - **3.1.1.1** Physical changes *e.g.*, changes to seafloor structure from deposition of feces, feed,(smothering) placement of netpen
     - **3.1.1.2** Chemical changes *e.g.*, addition of nutrients
     - **3.1.1.3** Biological changes *e.g.*, changes in benthic community structure
   - **3.1.2** Far field effects (including short and long term, resiliency of ecosystem to perturbation)
     - **3.1.2.1** Chemical changes *e.g.*, eutrophication, resuspension of nutrients, etc.
     - **3.1.2.2** Biological changes *e.g.*, algal growth, *etc*.
   - **3.1.3** Rates of Recovery *e.g.*, following fallowing or removal of netpens, change in redox following removal of site, length of time to see change in benthic community structure to recolonization

   3.2 Shellfish Aquaculture Review
   - **3.2.1** Near field effects including short and long term, resiliency of ecosystem to perturbation)
     - **3.2.1.1** Suspension Culture
       - Physical Changes *e.g.*, changes to seafloor structure from deposition of feces, placement of rafts, and shellfish drop-off
       - Chemical Changes *e.g.*, addition of nutrients
       - Biological Changes *e.g.*, changes in benthic community stucture
     - **3.2.1.2** On-bottom Culture (including beach culture, and sowing)
       - Physical Changes *e.g.*, direct changes to seafloor structure from epibenthic shellfish addition, and harvest activities
       - Chemical Changes *e.g.*, deposition of feces and nutrient addition
       - Biological Changes *e.g.*, benthic community changes
   - **3.2.2** Far field effects (including carrying capacity considerations)
     - **3.2.2.1** Suspension Culture
       - Chemical Changes
       - Biological Changes
     - **3.2.2.2** On-bottom Culture (including beach culture, and sowing)
       - Chemical Changes
       - Biological Changes
   - **3.2.3** Rates of Recovery
     - **3.2.3.1** Suspension
     - **3.2.3.2** On-bottom Culture (including beach culture, and sowing)

   3.3 Marine Algae
   - **3.3.1** Near field effects
     - **3.3.1.1** Physical changes (*e.g.*, change on circulation patterns (flow))
     - **3.3.1.2** Chemical changes (*e.g.*, reduction of nutrients)
     - **3.3.1.3** Biological changes (*e.g.*, creation of habitat for fish, biofouling)

- **3.3.2** Far field effects
  - **3.3.2.1** Chemical changes
  - **3.3.2.2** Biological changes (*e.g.*, causes green tide, epiphyte bloom, increase in productivity)
- **3.4** Polyculture/Integrated Multi-Trophic Aquaculture

4. Discussion, Analysis, Recommendations, Future (and FUTURE) Analysis

5. References

WG-24 Endnote 5

Proposal for a 1-day MEQ/FIS Topic Session at PICES-2011 on *"Identification and characterization of environmental interactions of marine aquaculture in the North Pacific"*

Convenors: Galina Gavrilova; Brett Dumbauld; Katsuyuki Abo

Marine aquaculture is an important economic and social activity within PICES member countries. To ensure development of aquaculture is environmentally and economically sustainable we need to: 1) improve our understanding of interactions between marine aquaculture and the environment (including wild stocks of plants and animals), 2) develop methods to study and/or predict such interactions, and 3) devise ways to reduce negative impacts on the environment. To this end the PICES Working Group on *Environmental Interactions of Marine Aquaculture* (WG 24) has begun to characterize the nature of these interactions with a focus on the benthic environment and aquatic animal health. To align with the activities of the WG 24 we propose to solicit papers in the following areas for this scientific session:

1. identification and characterization of marine aquaculture-environmental interactions;
2. development of tools to identify and study such interactions; and
3. social science research related to aquaculture interactions with the marine environment.

Duration: full day
A request was made for financial support for two invited speakers.

PICES Nineteenth Annual Meeting Topic Session Summary

FIS/MEQ Topic Session (S7)

Economic relation between marine aquaculture and wild capture fisheries

Co-Convenors: *Ingrid Burgetz (Canada), Dohoon Kim (Korea), Minling Pan (U.S.A.) and Qingyin Wang (China)*

Background

Considering the growing role of marine aquaculture in both seafood production and consumption as well as the close relationship between marine aquaculture and wild ocean capture fisheries, this session focused on the economic relationships of marine aquaculture to capture fisheries. Such relationships include (1) marine aquaculture products as a substitute and/or complement for wild caught products owing to consumer preference, price, and availability; (2) the synergies between aquaculture and fishing (use of fish processing trimmings, resilient coastal communities and maintaining working waterfronts), and (3) economic considerations regarding potential environmental effects (positive and negative), interactions between capture fisheries and marine aquaculture (*e.g.*, feed inputs in marine aquaculture derived from captured fisheries, aquaculture stock enhancement, and aquaculture structures as fish aggregating devices).

Summary of Presentations

This session was the first topic session on economics and social science at a PICES Annual Meeting. The past activities of PICES had mainly focused on physical and biological sciences, such as ecology, ecosystems, fisheries, oceanography, and biogeochemistry, *etc.* Topic session S7 was developed in response to the new FUTURE science program endeavors to provide a greater role for social and economic scientists in PICES. It was an important step toward enhancing research and management of marine living resources from a socio-economic perspective.

The session attracted broad participation of economists and experts from all the PICES member counties. This session consisted of 12 oral presentations, including 7 invited papers. The lead convenor, Minling Pan (U.S.A.), gave a brief introduction on the background and objectives of the topic session in the opening. The keynote speaker, Michael Rubino (U.S.A.), manager of the NOAA Aquaculture Program, outlined the economic issues and research needs raised by the potential expansion of domestic marine aquaculture, and in particular, the potential economic effects of marine aquaculture on capture fisheries. Dr. Rubino indicated that the economic ramifications of expanding aquaculture in the United States, along with environmental and food safety concerns, are the subject of much debate and widely differing views. Aquaculture may be a way to substantially increase domestic seafood production. Hatchery-based stock replenishment may be a way to restore depleted commercial and recreational fisheries. Associated economic benefits of these aquaculture activities may include the creation of jobs from coastal communities to the agricultural heartland, maintenance of working waterfronts, and synergies with commercial fishing such as use of fish processing trimmings. But concerns have been raised that domestic aquaculture may compete with domestic wild fisheries depressing prices for wild caught fish. Additional concerns include the economic consequences of potential environmental and social effects of aquaculture on wild capture fisheries and traditional fishing communities.

Other contributed papers reported case studies that discussed economic relations between marine aquaculture and wild capture fisheries from different aspects or demonstrated analytical models to measure the linkage/trade-off between these two. For example, Di Jin (U.S.A.) presented an integrated economic-ecological model developed for coastal New England by incorporating an aquaculture sector in the CGE model and by examining the forage fish and aquaculture link in a marine food web context. Yajie Liu (Norway) presented an analytical framework that aims to explore the ecological and economic impacts of genetic interaction between farmed and wild salmon over generations. The model was constructed based on the Atlantic salmon fishery and salmon farming in Norway. Hisashi Kurokura (Japan) illustrated how the development of the aquaculture industry (tuna culture) had influenced the consumer preference and consumption behaviors by cultured tuna in Japan. Kelly Davidson (U.S.A.) presented a study on consumer preferences for farm-raised *versus* wild-caught fish in Hawaii. Seong-Kwae Park (Korea) presented the historical trends of wild caught fish and farmed (marine) fish consumption in Korea. His study predicted that farmed fish would replace wild fish gradually, not rapidly, over time. Chen Sun (China) addressed the influence of marine aquaculture on the fishery industry supply chain and consumption in China. Both studies noticed that the economic trade-off between costs of sacrificing marine environmental quality and benefits from marine culture aquaculture expansion.

List of papers

Oral Presentations

Michael C. Rubino (Invited)
Potential economic effects on wild capture fisheries from an expansion of marine aquaculture in the United States

Di Jin (Invited)
Aquaculture and capture fisheries: An integrated economic-ecological analysis

Yajie Liu, Ola Diserud, Kjetil Hindar and Anders Skonhoft (Invited)
An ecological-economic model of genetic interaction between farmed and wild Salmon

Masahito Hirota and Yoshinobu Kosaka
The TASC (Total Allowable Scallop Culture) in Japan: An approach for the issue on the overproduction in Yezo giant scallop cultivation in Mutsu Bay

Heedong Pyo
Analyzing recovered effects of marine contaminated sediment cleanup project on wild capture fisheries in Korea

Galina S. Gavrilova
Capture fisheries and mariculture of the marine invertebrates in Peter the Great Bay (Japan Sea)

Toyomitsu Horii
Impacts on fishery products of the Tiger Puffer, *Takifugu rubripes*, by stock enhancement

Shang Chen, Li Wang, Tao Xia, Guoying Du and Dachuan Ren (Invited)
Quantification of maricultural effects on coastal ecosystems services: Sanggou Bay case from China

Seong-Kwae Park and Dong-Woo Lee (Invited)
Economic relation between marine aquaculture and wild capture fisheries: Case of Korea

Hisashi Kurokura, Akira Takagi, Yutaro Sakai and Nobuyuki Yagi (Invited)
Tuna goes around the world on sushi

Chen Sun (Invited)
The influence of marine aquaculture to the fishery industry chain in China

Kelly Davidson and Minling Pan (Invited)
Consumers' willingness to pay for aquaculture fish products *vs.* wild-caught seafood – A case study in Hawaii

PICES Twentieth Annual Meeting, PICES-2011
October 14–23, 2011
Khabarovsk, Russia

Report of Working Group 24 on *Environmental Interactions of Marine Aquaculture*

The Working Group on *Environmental Interactions of Marine Aquaculture* (WG 24) held its final meeting on October 15, 2011, in Khabarovsk, Russia. The meeting was co-chaired by Drs. Katsuyuki Abo and Stewart Johnson (for Ms. Ingrid Burgetz). A list of participants and the meeting's agenda can be found in *WG 24 Endnotes 1* and *2*.

AGENDA ITEM 2

Overview of Working Group 24 commitments from 2010

Dr. Abo provided a brief review of the Working Group commitments which were made at the 2010 Annual Meeting in Portland, Oregon, USA.

AGENDA ITEM 3

Presentation and discussion on Terms of Reference 1 activities and report

Dr. Abo is leading this part of the Working Group activities which is examining the "environmental interactions of aquaculture". He has received country reports from most of the PICES member countries with the exception of U.S. and China. The goal is to have all country reports completed by December 1, 2012. The Co-chairs and Dr. Stewart Johnson will summarize and complete the final report for TOR1.

AGENDA ITEM 4

Presentation and discussion on Terms of Reference 2 report and opportunity for final additions

Ms. Burgetz is leading this part of the Working Group activities which is examining the current "risk assessment methods used to assess environmental interactions of aquaculture". Unfortunately, Ms. Burgetz was unable to attend the meeting but it was reported that she will finalize the report for TOR2 (risk assessment) based on submissions that have been made by PICES member countries. Modification of country reports will be completed by December 1, 2011. The final report will be completed by September 1, 2012.

AGENDA ITEM 5

Presentation and discussion on Terms of Reference 3 activities and report

In order to collect information for TOR3, member countries were provided in 2010 with a template to complete. Dr. L. Gustafson (USA) is compiling this information, which will be used in the production of the final report. The Working Group is planning to also use this information to produce a review paper on Diseases and Disease Regulations in PICES member countries that will be submitted for publication in a peer reviewed journal. Information has been received from all member countries except China, who will submit this information on or before December 1, 2011.

AGENDA ITEM 6

Discussion on finalizing reports for each of the Terms of Reference

For a number of reasons WG 24 was not able to complete its final report in 2010/11. The Working Group requested an extension to enable completion of the final report. The schedule for production of the final report is as follows:
December 1, 2011: final input from all member countries on all Terms of Reference;
May 1, 2012: draft reports will be completed and circulated for members comments;
July 1, 2012: deadline for receipt of comments from Working Group Members;
September 1, 2012: completion of final Working Group report to all Working Group members and the PICES Secretariat.

The Co-Chairs and Dr. Johnson will compile and edit the final version of the WG 24 report.

AGENDA ITEM 7

Summary of Working Group activities and report to Committees

A summary of Working Group activities over the past year was reported by Dr. Abo to the FIS and MEQ parent committee meetings at PICES-2011.

AGENDA ITEM 8

Discussion on future activity of mariculture issues within PICES

Members of the Working Group were in agreement that aquaculture remains an important topic for PICES and the FUTURE Program. Dr. Galina Gavrilova (Russia) suggested the extension of WG 24 for 1 year to allow us to complete the final report and to develop a proposal for a study group. Upon further discussion, the Group consensus was that, following approval of the United States, an application for a study group related to aquaculture would be put forward at the 2012 PICES Annual Meeting. The focus of this study group and its Terms of Reference will be developed over the next year, taking into consideration the direction of Working Group on Development of Ecosystem Indicators to Characterize Ecosystem Responses to Multiple Stressors (WG 28) and other FUTURE activities. Members of WG 24 and others will contribute to this activity.

Action Item: WG 24 members will be contacted to determine whether they are in favor of developing a study group proposal for consideration at the PICES-2012. Members will be requested to provide suggestions from which Terms of Reference and the objectives of such a study group can be developed.

AGENDA ITEM 9

Topic Session S6 at PICES-2011

A half-day MEQ/FIS Topic Session on "*Identification and characterization of environmental interactions of marine aquaculture in the North Pacific*" was held at PICES-2011. This session included invited oral presentations by Dr. Sakami (Japan) and Dr. Dong (China). Eight oral and 3 poster presentations given.

Following the presentations there was a brief discussion of WG 24's plan to propose a study group at the next PICES Annual Meeting in Hiroshima, Japan. Participants were requested to contact Working Group members over the next year with their suggestions and ideas.

WG 24 Endnote 1

WG 24 participation list

<u>Members</u>

Katsuyuki Abo (Japan, Co-Chair)
Galina Gavrilova (Russia)
Graham Gillespie (Canada)
Toyomitsu Horii (Japan)
Stewart Johnson (Canada, Acting Co-Chair for Ingrid Burgetz)
Hyun-Jeong Lim (Korea)
Myoung-Ae Park (Korea)
Ping Zhuang (China)

<u>Observers</u>

Natsuki Haseqawa (Japan)
Yukimasa Ishida (Japan)
Tomoko Sakami (Japan)
Mikhail Stepanenko (Russia)
Mingyuan Zhu (China)

WG 24 Endnote 2

WG 24 meeting agenda

1. Welcome and Introductions (Chairs: Katsuyuki Abo and Stewart Johnson)
2. Overview of WG commitments from 2010 (Abo)
3. Presentation and discussion on TOR1 activities and report (Facilitated discussion: Katsuyuki Abo – facilitator)
4. Overview of TOR2 report and opportunity for final additions (Facilitated discussion: Stewart Johnson – facilitator)
5. Presentation and discussion on TOR3 activities and report (Facilitated discussion: Stewart Johnson – facilitator)
6. Discussion on finalizing reports for each of the TOR
7. Summary of WG activities and report to Committees
8. Discussion on future activity of mariculture issues within PICES
9. Topic Session S6 on "*Identification and characterization of environmental interactions of marine aquaculture in the North Pacific*" at PICES-2011

PICES Twentieth Annual Meeting Topic Session Summary

MEQ/FIS Topic Session (S6)
Identification and characterization of environmental interactions of marine aquaculture in the North Pacific

Co-Convenors: *Katsuyuki Abo (Japan), Brett Dumbauld (U.S.A.) and Galina Gavrilova (Russia)*

Invited Speakers:
Tomoko Sakami (Tohoku National Fisheries Research Institute, Japan)
Shuanglin Dong (Ocean University of China, PR China)

Background

Marine aquaculture is an important economic and social activity within PICES member countries. To ensure that development of aquaculture is environmentally and economically sustainable we need to: 1) improve our understanding of interactions between marine aquaculture and the environment (including wild stocks of plants and animals, 2) develop methods to study and/or predict such interactions, and 3) devise ways to reduce negative impacts on the environment. To this end the PICES Working Group on *Environmental Interactions of Marine Aquaculture* has begun to characterize the nature of these interactions with a focus on the benthic environment and aquatic animal health. To align with the activities, papers for this session are solicited in the following areas: 1) identification and characterization of marine aquaculture-environmental interactions; 2) development of tools to identify and study such interactions; and 3) social science research related to aquaculture interactions with the marine environment.

Summary of Presentations

The presentations covered a variety of applications of marine aquaculture in PICES countries. There were 2 invited oral presentations, 6 oral presentations and 3 posters prepared for this session from Canada, China, Japan, Russia and USA. Two oral presentations were cancelled but one alternative oral presentation was presented by Dr. Hasegawa. About 50 people participated in the topic session.

The invited speaker, Dr. Tomoko Sakami (Fisheries Research Agency, Japan) started the session by describing an attempt to assess aquaculture environments using microbial communities in bottom sediments. She suggested sedimentary microbe genomic information is a prospective parameter to assess the environments influenced by fish aquaculture (Abstract S6-7567). Another invited speaker, Dr. Shuanglin Dong introduced integrated aquaculture in China. He described the history, ecological rationales, classification and development of integrated aquaculture in China (Abstract S6-7755).

Dr. Katsuyuki Abo summarized research on environmental interactions of marine aquaculture in Japan. He reviewed studies on impacts of marine aquaculture on benthic environments to identify and characterize the environmental interaction of marine aquaculture in Japan (Abstract S6-7736). Due to visa application trouble, Dr. Brett Dumbauld was unable to attend the topic session so an alternative presentation was given by Dr. Natsuki Hasegawa. He discussed the use of aquaculture species for monitoring change in coastal ecosystems and fisheries productions. He suggested bivalves and seaweed species for aquaculture as potential indicators of coastal ecosystem production (Abstract S6-7665-2; provided as *Endnote 1*). Dr. Stewart Johnson presented an overview of interactions between wild and farmed salmonids in Southern British Columbia. He summarized surveys of pathogens in wild salmonids, laboratory studies on pathogens and hosts, improved diagnostic methods and the use of physical oceanographic models to predict pathogen movements within the environment (Abstract S6-7861). The influence of environmental factors on hanging plantations for *Laminaria* kelp was presented by Dr. Tatiana Krupnova (Abstract S6-7858). Dr. Sei-Ichi Saitoh discussed the use of GIS-based spatial models to select Japanese kelp aquaculture sites in the Southwestern Hokkaido (Abstract S6-7580).

Dr. Chunjiang Guan presented a poster on absorption of carbon and nitrogen by culturing *Sargassum thunbergii* in coastal waters. He suggested *Sargassum thunbergii* culture played an important role in restoring eutrophied sea waters and in absorbing CO_2.

At the end of the topic session, a proposed plan for a new SG at 2012 AGM was introduced to participants and ideas and suggestions of participants were requested during this year.

List of papers

Oral presentations

Tomoko Sakami, Ryuji Kondo and Takanori Bobayashi (Invited)
An attempt to assess the environment by using microbial communities of the bottom sediments from marine areas of fish aquaculture

Shuanglin Dong (Invited)
Integrated aquaculture in China

Katsuyuki Abo
Environmental interactions of marine aquaculture in Japan

Natsuki Haseqawa and Toshihiro Onitsuka
Monitoring the change of coastal ecosystem and fisheries productions using an aquaculture system

Stewart Johnson, Michael Foreman, Kyle Garver, Brent Hargreaves, Simon R.M. Jones and Chrys Neville
Interactions between wild and farmed salmonids in Southern British Columbia: Pathogen transfer

Tatiana Krupnova, Vladimir Pavlutcykov and Nina Shepel
Environmental influences on harvesting from hanging plantations for *Laminaria* kelp

Nyoman Radiarta, Sei-Ichi Saitoh, Toru Hirawake and Hajime Yasui
GIS-based spatial models for Japanese kelp (*Laminaria japonica*) aquaculture site selection in the Southwestern Hokkaido, Japan

Wei Zheng, Honghua Shi, Xuelei Zhang, Mingyuan Zhu and Zongling Wang
Ecological-economic assessment of monoculture and integrated multi-trophic aquaculture in Sanggou Bay, China

Endnote 1

Abstract of the alternative presentation, S6-7665-2

Monitoring the change of coastal ecosystem and fisheries productions using an aquaculture system

Natsuki **Hasegawa** and Toshihiro Onitsuka

Hokkaido National Fisheries Research Institute, FRA, 116 Katsurakoi, Kushiro, Hokkaido, 085-0802, Japan
E-mail: hasena@fra.affrc.go.jp

Linking changes in ecosystem and fisheries production with environmental factors which contribute to numerical models that predict that change is particularly difficult in coastal areas. Since there are more diverse organisms, landscapes, and interactions in coastal areas than those in offshore areas, change was not directly predicted by numerical models. Bivalves and seaweed species for aquaculture are potential indicators of coastal ecosystem production, because these primary consumers and producers are sensitive to environmental changes especially at early stages. However, changes in catch or landings do not reflect change in productivity and there might not be enough objective and scientific data on parameters like number and survival rate to estimate production in Japanese aquaculture using catch or landings alone. Therefore constructing a broad monitoring system of these productivity indices and other characteristics, which could be routinely collected with aquaculture, would be useful for analyzing catch data and for identifying change. Accumulation of these short-term data would effectively contribute to predicting mid and long term change in coastal ecosystem and fisheries production based on predictive environmental models.

Poster Presentations

Chunjian Guan and Feng'ao Lin
Absorption of carbon and nitrogen by culuring *Sarassum thunbergii* in coastal waters

Vera Valova
The influence of salmon hatchery conditions on the physiological status of Amur sturgeon

Olga G. Shevchenko
Monitoring of potentially toxic microalgae in Severnaya Bight (Slavyanskii Bay, the Sea of Japan) in 2008, 2009

Appendix 4

PICES Press Article

A New PICES Working Group Holds Workshop and Meeting in Jeju Island

by Kevin Amos and Katsuyuki Abo

The newly formed PICES Working Group on *Environmental Interactions of Marine Aquaculture* (WGEIMA; WG 24) convened its inaugural meeting and sponsored a workshop at the 2009 PICES Annual Meeting held in October, in Jeju, Korea. This Working Group operates under the auspices of the Marine Environmental Quality (MEQ) and Fishery Science (FIS) Committees.

As marine aquaculture evolves around the world, significant fish and shellfish culture activities are occurring in PICES member countries. Considering that the potential exists for interactions to occur between culture facilities and the surrounding ecosystems, WGEIMA has embarked on an effort to better understand these interactions and assess their risk. Our primary mission is to develop standard methods and tools to assess and compare the environmental interactions and characteristics of existing and planned marine aquaculture activities in PICES member countries. The following action plan (terms of reference) were approved at the formation of WGEIMA:

1. Evaluate approaches currently being used in PICES member countries to assess and model the interactions of aquaculture operations with surrounding environments. (This will involve conducting a comparative assessment of the methodologies, applications, and outputs of different approaches to assess finfish, shellfish, seaweed, and/or integrated multi-tropic aquaculture.)
2. Review and evaluate current risk assessment methods used to assess environmental interactions of aquaculture and determine what, if anything, should be changed for their application in PICES member countries to reflect ecosystem-specific aspects. Following the review and assessment, identify appropriate case studies to compare results among countries in the PICES region. (This will be achieved by holding a workshop in the second or third year to compare and discuss possible standardization of methodologies and the selection of potential case studies for assessment with a standardized approach. Functions and responsibilities of the sub-group undertaking this task will be similar to the ICES Working Group on *Environmental Interactions of Mariculture*, so the feasibility of holding a joint meeting with this group will be explored.)
3. Assess methods to detect, identify, evaluate and report on infectious disease events and potential interactions between wild and farmed marine animals. If appropriate, develop a recommended standardized approach for detection/evaluation/reporting from wild and cultured populations. The focus of this activity will be on OIE-notifiable diseases and other infectious diseases of regional/economic importance. (This will involve discussing and documenting new and emerging infectious diseases in the PICES region, methods for their detection, and developing models to conduct risk assessments of their potential impacts on both endemic wild and farmed species. Functions and responsibilities of the sub-group undertaking this task will be similar to the ICES Working Group on *Pathology and Diseases of Marine Organisms*, so the feasibility to hold a joint meeting will be explored.)

On October 24, WGEIMA held it first major activity – a workshop on "*Interactions between aquaculture and marine ecosystems*" co-convened by Katsuyuki Abo (Japan), Kevin Amos (U.S.A.), Galina Gavrilova (Russia) and Hyun Jeong Lim (Korea). The major objective of the workshop was to discuss tools and models currently used by PICES member countries to evaluate interactions of marine aquaculture and assess the risks of these interactions. Three noted experts were invited to the workshop to share with us their models and research. Dr. Dario Stucchi (Fisheries and Oceans Canada) has been studying how currents, tides, and other oceanographic conditions disperse sea lice larvae from salmon farms to the marine ecosystems in the Broughton Archipelago, British Columbia, Canada. There is concern that lice from salmon farms may be infecting, and subsequently impacting, wild salmon populations, and Dr. Stucchi's models will be utilized in helping to better understand this potential pathogen interaction.

The fate of effluent and nutrients from marine farms is the focus of *AquaModel* developed by Dr. Jack Rensel (Rensel Associates Aquatic Sciences, U.S.A.). Like Dr. Stucchi's models, his model explores physical and chemical oceanographic phenomena to determine if and how effluents from fish farms may interact with marine ecosystems. His data suggest that improperly sited farms may have negative impacts while properly sited farms have no impact or possible benefits on nutrient-poor ecosystems.

Dr. Tamiji Yamamoto (Hiroshima University, Japan) has been focusing on effects of culture density on the growth and fecal production of the oyster *Crassostrea gigas* in Hiroshima Bay. His model expresses physiological processes of the oyster as well as physical and chemical oceanographic phenomena. His study has suggested the appropriate cultivation density under the environmental conditions of the Bay.

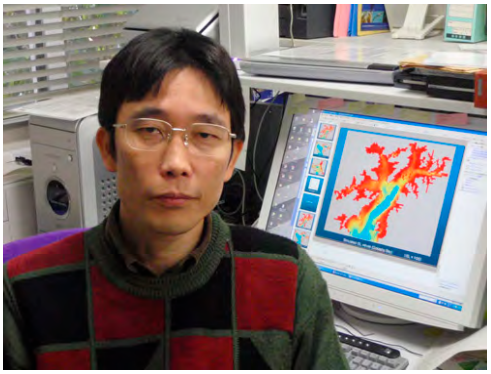
Many other speakers presented interesting research on various aspects of marine aquaculture, including possible interactions of effluents, pathogens, and genetics. Brief information on all presentations can be found in the Book

Participants of the WGEIMA workshop and meeting at the end of a field trip, October 25, 2009, Jeju, Korea.

of Abstracts for PICES-2009, along with contact information for each author.

After the successful workshop, WGEIMA held a half-day meeting to discuss the next steps to be taken. In the near term, we will attempt to reach consensus on types/methodologies of aquaculture that have commonality in all PICES member countries and then start to identify and develop risk assessments associated with these technologies. For more details on the meeting please refer to the 2009 PICES Annual Report. Next time, WGEIMA will meet in conjunction with the 2010 PICES Annual Meeting (Portland, U.S.A.), but there will be much interaction among the Working Group members before we gather together again in Portland.

Our activities in Jeju were capped off by an excellent field trip hosted by Korea and organized by Dr. Hyun Jeong Lim. This half-day trip took us first to a flounder aquaculture farm operated by *Bibong Aquaculture*. The flounder were being raised in land-based concrete tanks with seawater being pumped through volcanic rock immediately adjacent to the ocean. Our next stop was an abalone farm operated by *Jeil Hatchery*. Like the flounder farm, this farm was utilizing pumped seawater into land-based tanks. The abalone are fed kelp and take 3 to 4 years to reach market size. Our final stop was a visit to a Korean Culture Park that exhibited the various life styles, dwellings, and historic farming techniques utilized by the Korean natives in the countryside. All participants greatly enjoyed the trip – thanks Dr. Lim!!!



Dr. Kevin Amos (Kevin.Amos@noaa.gov) is the Aquatic Animal Health Coordinator for the U.S. National Marine Fisheries Service. His professional interests include aquatic animal health policy, international commerce of aquatic products, and marine aquaculture. In PICES, Kevin serves as Co-Chairman of the Working Group on Environmental Interactions of Marine Aquaculture. Out of the office you might find Kevin on the golf course or pursuing salmon with a rod and reel.

Dr. Katsuyuki Abo (abo@fra.affrc.go.jp) is a senior researcher at the National Research Institute of Aquaculture, Fisheries Research Agency, Japan. His research focuses on water and benthic qualities of marine aquaculture area, using numerical models to estimate the assimilative capacity. His scientific interest includes modeling study to predict occurrences of harmful algal blooms and oxygen depletion in coastal seas. In PICES, Katsuyuki co-chairs the Working Group on Environmental Interactions of Marine Aquaculture.

Continued from inside back cover

Jamieson, G. and Zhang, C.-I. (Eds.) 2005. Report of the Study Group on Ecosystem-Based Management Science and its Application to the North Pacific. **PICES Sci. Rep. No. 29**, 77 pp.

Brodeur, R. and Yamamura, O. (Eds.) 2005. Micronekton of the North Pacific. **PICES Sci. Rep. No. 30**, 115 pp.

Takeda, S. and Wong, C.S. (Eds.) 2006. Report of the 2004 Workshop on *In Situ* Iron Enrichment Experiments in the Eastern and Western Subarctic Pacific. **PICES Sci. Rep. No. 31**, 187 pp.

Miller, C.B. and Ikeda, T. (Eds.) 2006. Report of the 2005 Workshop on Ocean Ecodynamics Comparison in the Subarctic Pacific. **PICES Sci. Rep. No. 32**, 103 pp.

Kruse, G.H., Livingston, P., Overland, J.E., Jamieson, G.S., McKinnell, S. and Perry, R.I. (Eds.) 2006. Report of the PICES/NPRB Workshop on Integration of Ecological Indicators of the North Pacific with Emphasis on the Bering Sea. **PICES Sci. Rep. No. 33**, 109 pp.

Hollowed, A.B., Beamish, R.J., Okey, T.A. and Schirripa, M.J. (Eds.) 2008. Forecasting Climate Impacts on Future Production of Commercially Exploited Fish and Shellfish. **PICES Sci. Rep. No. 34**, 101 pp.

Beamish, R.J. (Ed.) 2008. Impacts of Climate and Climate Change on the Key Species in the Fisheries in the North Pacific. **PICES Sci. Rep. No. 35**, 217 pp.

Kashiwai, M. and Kantakov, G.A. (Eds.) 2009. Proceedings of the Fourth Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 36**, 305 pp.

Jamieson, G., Livingston, P. and Zhang, C.-I. (Eds.) 2010. Report of Working Group 19 on Ecosystem-based Management Science and its Application to the North Pacific. **PICES Sci. Rep. No. 37**, 166 pp.

Pakhomov, E. and Yamamura, O. (Eds.) 2010. Report of the Advisory Panel on Micronekton Sampling Inter-calibration Experiment. **PICES Sci. Rep. No. 38**, 108 pp.

Makino, M. and Fluharty, D.L. (Eds.) 2011. Report of the Study Group on Human Dimensions. **PICES Sci. Rep. No. 39**, 40 pp.

Foreman, M.G. and Yamanaka, Y. (Eds.) 2011. Report of Working Group 20 on Evaluations of Climate Change Projections. **PICES Sci. Rep. No. 40**, 165 pp.

McKinnell, S.M., Curchitser, E., Groot, C., Kaeriyama, M. and Myers, K.W. 2012. PICES Advisory Report on the Decline of Fraser River Sockeye Salmon *Oncorhynchus nerka* (Steller, 1743) in Relation to Marine Ecology. **PICES Sci. Rep. No. 41**, 149 pp.

Takeda, S., Chai, F. and Nishioka, J. (Eds.) 2013. Report of Working Group 22 on Iron Supply and its Impact on Biogeochemistry and Ecosystems in the North Pacific Ocean. **PICES Sci. Rep. No. 42**, 60 pp.

Shaw, C.T., Peterson, W.T. and Sun, S. (Eds.) 2013. Report of Working Group 23 on Comparative Ecology of Krill in Coastal and Oceanic Waters around the Pacific Rim. **PICES Sci. Rep. No. 43**, 100 pp.

Abo, K., Burgetz, I. and Dumbauld, B. (Eds.) 2013. Report of Working Group 24 on Environmental Interactions of Marine Aquaculture. **PICES Sci. Rep. No. 44**, 122 pp.

PICES Scientific Reports

Hargreaves, N.B., Hunter, J.R., Sugimoto, T. and Wada, T. (Eds.) 1993. Coastal Pelagic Fishes (Report of Working Group 3); Subarctic Gyre (Report of Working Group 6). **PICES Sci. Rep. No. 1**, 130 pp.

Talley, L.D. and Nagata, Y. (Eds.) 1995. The Okhotsk Sea and Oyashio Region (Report of Working Group 1). **PICES Sci. Rep. No. 2**, 227 pp.

Anonymous. 1995. Report of the PICES-STA Workshop on Monitoring Subarctic North Pacific Variability. **PICES Sci. Rep. No. 3**, 94 pp.

Hargreaves, N.B. (Ed.) 1996. Science Plan, Implementation Plan (Report of the PICES-GLOBEC International Program on Climate Change and Carrying Capacity). **PICES Sci. Rep. No. 4**, 64 pp.

LeBlond, P.H. and Endoh, M. (Eds.) 1996. Modelling of the Subarctic North Pacific Circulation (Report of Working Group 7). **PICES Sci. Rep. No. 5**, 91 pp.

Anonymous. 1996. Proceedings of the Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 6**, 426 pp.

Beamish, R.J., Hollowed, A.B., Perry, R.I., Radchenko, V.I., Yoo, S. and Terazaki, M. (Eds.) 1997. Summary of the Workshop on Conceptual/Theoretical Studies and Model Development and the 1996 MODEL, BASS and REX Task Team Reports. **PICES Sci. Rep. No. 7**, 93 pp.

Nagata, Y. and Lobanov, V.B. (Eds.) 1998. Multilingual Nomenclature of Place and Oceanographic Names in the Region of the Okhotsk Sea. **PICES Sci. Rep. No. 8**, 57 pp. (Reprint from MIRC Science Report, No. 1, 1998)

Hollowed, A.B., Ikeda, T., Radchenko, V.I. and Wada, T. (Organizers) 1998. PICES Climate Change and Carrying Capacity Workshop on the Development of Cooperative Research in Coastal Regions of the North Pacific. **PICES Sci. Rep. No. 9**, 59 pp.

Freeland, H.J., Peterson, W.T. and Tyler, A. (Eds.) 1999. Proceedings of the 1998 Science Board Symposium on The Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and Its Marginal Seas. **PICES Sci. Rep. No. 10**, 110 pp.

Dugdale, R.C., Hay, D.E., McFarlane, G.A., Taft, B.A. and Yoo, S. (Eds.) 1999. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Summary of the 1998 MODEL, MONITOR and REX Workshops, and Task Team Reports. **PICES Sci. Rep. No. 11**, 88 pp.

Lobanov, V.B., Nagata, Y. and Riser, S.C. (Eds.) 1999. Proceedings of the Second PICES Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 12**, 203 pp.

Danchenkov, M.A., Aubrey, D.G. and Hong, G.H. 2000. Bibliography of the Oceanography of the Japan/East Sea. **PICES Sci. Rep. No. 13**, 99 pp.

Hunt, G.L. Jr., Kato, H. and McKinnell, S.M. (Eds.) 2000. Predation by Marine Birds and Mammals in the Subarctic North Pacific Ocean. **PICES Sci. Rep. No. 14**, 168 pp.

Megrey, B.A., Taft, B.A. and Peterson, W.T. (Eds.) 2000. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 1999 MONITOR and REX Workshops, and the 2000 MODEL Workshop on Lower Trophic Level Modelling. **PICES Sci. Rep. No. 15**, 148 pp.

Stehr, C.M. and Horiguchi, T. (Eds.) 2001. Environmental Assessment of Vancouver Harbour Data Report for the PICES MEQ Practical Workshop. **PICES Sci. Rep. No. 16**, 213 pp.

Megrey, B.A., Taft, B.A. and Peterson, W.T. (Eds.) 2001. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 2000 BASS, MODEL, MONITOR and REX Workshops, and the 2001 BASS/MODEL Workshop. **PICES Sci. Rep. No. 17**, 125 pp.

Alexander, V., Bychkov, A.S., Livingston, P. and McKinnell, S.M. (Eds.) 2001. Proceedings of the PICES/CoML/IPRC Workshop on "Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific". **PICES Sci. Rep. No. 18**, 210 pp.

Otto, R.S. and Jamieson, G.S. (Eds.) 2001. Commercially Important Crabs, Shrimps and Lobsters of the North Pacific Ocean. **PICES Sci. Rep. No. 19**, 79 pp.

Batchelder, H.P., McFarlane, G.A., Megrey, B.A., Mackas, D.L. and Peterson, W.T. (Eds.) 2002. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the 2001 BASS/MODEL, MONITOR and REX Workshops, and the 2002 MODEL/REX Workshop. **PICES Sci. Rep. No. 20**, 176 pp.

Miller, C.B. (Ed.) 2002. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: Report of the PICES 2002 Volunteer Observing Ship Workshop. **PICES Sci. Rep. No. 21**, 38 pp.

Perry, R.I., Livingston, P. and Bychkov, A.S. (Eds.) 2002. PICES Science: The First Ten Years and a Look to the Future. **PICES Sci. Rep. No. 22**, 102 pp.

Taylor, F.J.R. and Trainer, V.L. (Eds.) 2002. Harmful Algal Blooms in the PICES Region of the North Pacific. **PICES Sci. Rep. No. 23**, 152 pp.

Feely, R.A. (Ed.) 2003. CO_2 in the North Pacific Ocean (Working Group 13 Final Report). **PICES Sci. Rep. No. 24**, 49 pp.

Aydin, K.Y., McFarlane, G.A., King, J.R. and Megrey, B.A. (Eds.) 2003. PICES-GLOBEC International Program on Climate Change and Carrying Capacity: The BASS/MODEL Report on Trophic Models of the Subarctic Pacific Basin Ecosystems. **PICES Sci. Rep. No. 25**, 93 pp.

McKinnell, S.M. (Ed.) 2004. Proceedings of the Third Workshop on the Okhotsk Sea and Adjacent Areas. **PICES Sci. Rep. No. 26**, 275 pp.

Kishi, M.J. (Ed.) 2004. Report of the MODEL Task Team Second Workshop to Develop a Marine Ecosystem Model of the North Pacific Ocean including Pelagic Fishes. **PICES Sci. Rep. No. 27**, 49 pp.

King, J.R. (Ed.) 2005. Report of the Study Group on the Fisheries and Ecosystem Responses to Recent Regime Shifts. **PICES Sci. Rep. No. 28**, 162 pp.

Continued on inside back page

PICES PUBLICATIONS

The North Pacific Marine Science Organization (PICES) was established by an international convention in 1992 to promote international cooperative research efforts to solve key scientific problems in the North Pacific Ocean.

PICES regularly publishes various types of general, scientific, and technical information in the following publications:

PICES ANNUAL REPORTS – are major products of PICES Annual Meetings which document the administrative and scientific activities of the Organization, and its formal decisions, by calendar year.

PICES SCIENTIFIC REPORTS – include proceedings of PICES workshops, final reports of PICES expert groups, data reports and planning reports.

PICES TECHNICAL REPORTS – are on-line reports published on data/monitoring activities that require frequent updates.

SPECIAL PUBLICATIONS – are products that are destined for general or specific audiences.

JOURNAL SPECIAL ISSUES – are peer-reviewed publications resulting from symposia and Annual Meeting scientific sessions and workshops that are published in conjunction with commercial scientific journals.

BOOKS – are peer-reviewed, journal-quality publications of broad interest.

PICES PRESS – is a semi-annual newsletter providing timely updates on the state of the ocean/climate in the North Pacific, with highlights of current research and associated activities of PICES.

ABSTRACT BOOKS – are prepared for PICES Annual Meetings and symposia (co-)organized by PICES.

For further information on our publications, visit the PICES website at www.pices.int.

Front cover figure

(From top) Japanese colleagues visiting Russian scientists at a sea cucumber hatchery in Kievka Bay, Russia; intertidal geoduck clam (*Panopea generosa*) aquaculture in southern Puget Sound, Washington State, USA. Juvenile clams are planted in tubes for predator protection; intertidal long-line oyster (*Crassostrea gigas*) culture in Humboldt Bay, California, USA (photo credits: Andy Suhrbier, Pacific Shellfish Institute); fish farming in Kumano-nada, Japan. Red sea bream (*Pagrus major*) and yellowtail (*Seriola quinqueradiata*) are cultured in floating net pens (photo credit: Hisashi Yokoyama, National Research Institute of Aquaculture, FRA).