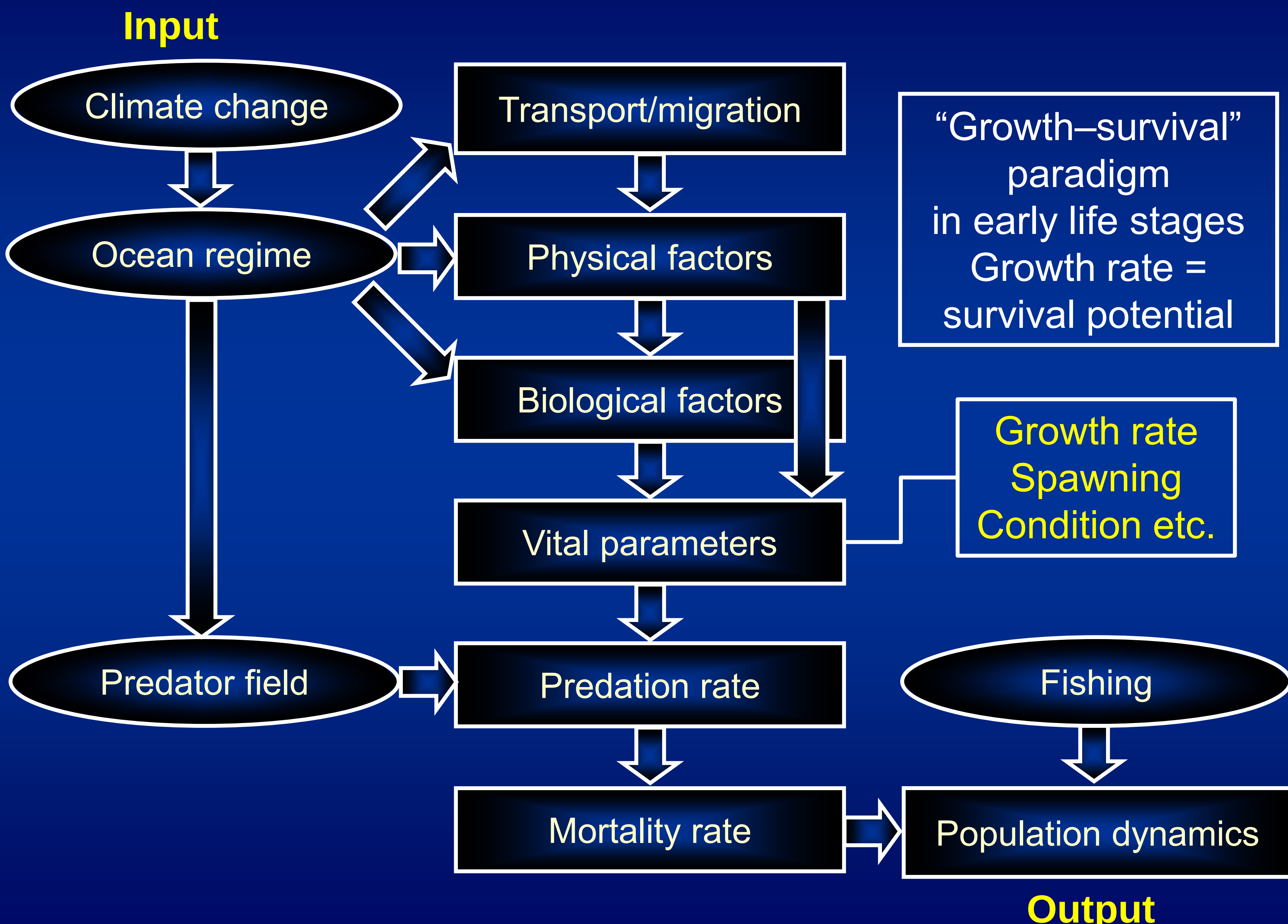
Reaching consensus on the growth–survival paradigm in early life stages of fish

Akinori Takasuka, Dominique Robert, Jun Shoji, Pascal Sirois, Louis Fortier, Yoshioki Oozeki, Pierre Pepin, Arild Folkvord, Myron A. Peck, Ignacio A. Catalán, Alberto G. García, Richard D. Brodeur, Su Sponaugle, Evan K. D’Alessandro, Stuart A. Ludsin, Klaus B. Huebert, Marc Hufnagl, John F. Dower, Guido Plaza, Patricia M. Ayón, Naoki Tojo, Mikimasa Joh, Shin-ichi Ito, Yosuke Tanaka, Motomitsu Takahashi, Francis Juanes, Emily Y. Campbell, Patricia Reglero, Naotaka Yasue, Shingo Watari, Mitsuo Nyuji
(31 co-authors from Japan, Canada, Norway, Germany, Spain, USA, Chile, and Perú)

Symposium on “Drivers of dynamics of small pelagic fish resources”
Victoria Conference Centre, Victoria, BC, Canada
W4 “*Modeling migratory fish behavior and distribution*”
Invited talk, March 11, 2017

Takasuka *et al*.

Cascade



Background

Growth–survival paradigm (GSP)
in early life stages of fish

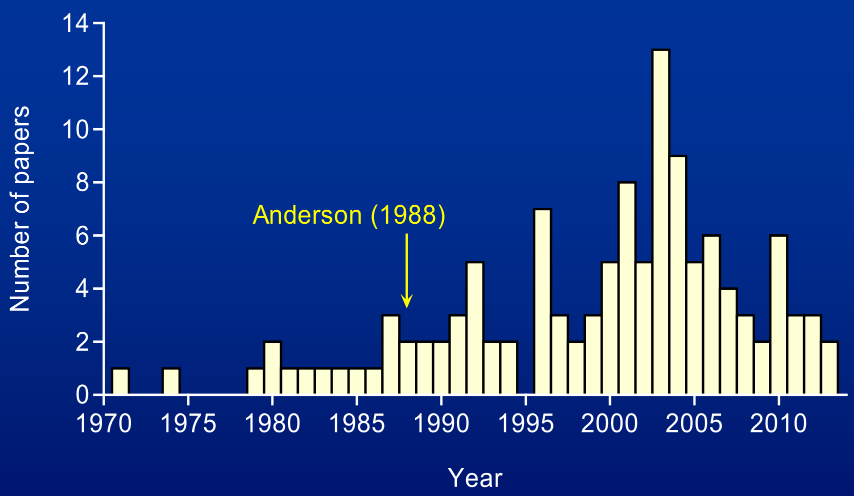
"Larger and/or faster growing individuals are more likely to survive than smaller and/or slower growing conspecifics"

History

- "Growth–mortality" hypothesis (Anderson 1988 *JNAFS*)

Progresses

- Numerous field, laboratory, and modeling studies have tested the paradigm.
- Contributing to early life biology and recruitment studies.



Number of published studies which include GSP tests.

Background

Quick review

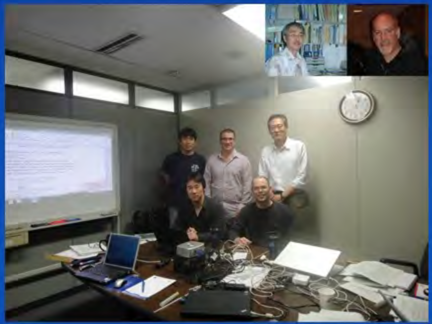
1. Previous field studies tended to support the paradigm/ mechanisms.
2. Some laboratory studies provided evidence contrary to the paradigm/mechanisms.
3. Recent studies showed a variability of direction of selective survival and dynamics of the mechanisms.

Current status

- The actual growth–survival relationships seem to be much more variable and dynamic than previously recognized.
- Predicting recruitment dynamics from early growth dynamics has revealed difficult.

It is time to review studies on GSP after Anderson (1988).

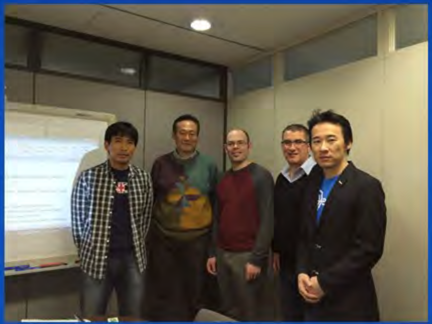
GSP workshop in 2011



Japan–Québec collaboration workshop on
“Growth–survival paradigm in early life stages of fish: theory, advance, synthesis, and future”
Yokohama, Japan
October 26 – November 1, 2011

科研費 KAKENHI FRA Québec Océan

Follow-up workshop in 2013



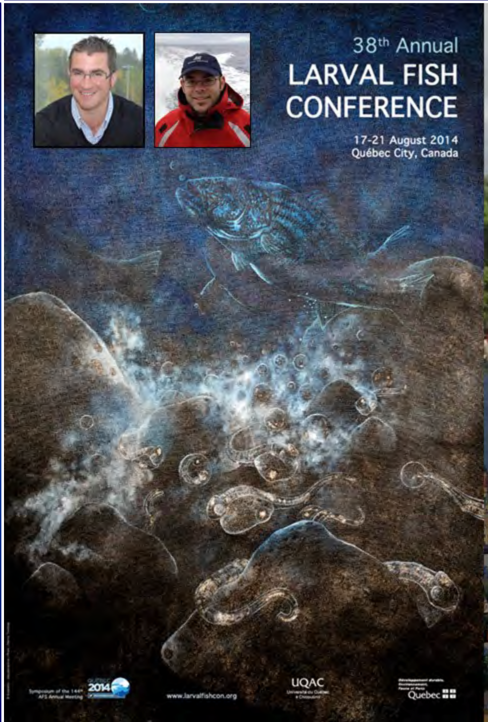
Japan–Canada collaboration workshop on
“Growth–survival paradigm in early life stages of fish: theory, advance, synthesis, and future” Part III
Yokohama, Japan
November 8–15, 2013

科研費 KAKENHI FRA Québec Océan

Follow-up workshop in 2012

Japan–Québec collaboration workshop on
“Growth–survival paradigm in early life stages of fish: theory, advance, synthesis, and future” Part II
Vancouver, Canada
May 23–26, 2012

科研費 KAKENHI FRA Québec Océan



Growth–survival paradigm in early life stages of fish

I. Theory

Summarizing a theoretical framework of the current paradigm and its functional mechanisms

II. Advance

Reviewing recent advances in studies on the paradigm

III. Synthesis

Proposing a conceptual framework which reconciles contradictory evidence from field, laboratory, and modeling studies across systems and taxa

IV. Future

Presenting recommendations for future study directions

Theory

Growth–survival paradigm (GSP)
in early life stages of fish

"Larger and/or faster growing individuals
are more likely to survive than
smaller and/or slower growing conspecifics"

Survival advantages of faster-growing individuals
Why do they survive better?

Functional mechanisms

1. "Bigger is better" (Miller *et al*. 1988 *CJFAS*)
2. "Stage duration" (Chambers & Leggett 1987 *CJFAS*, Houde 1987 *AFSS*)
3. "Growth-selective predation" (Takasuka *et al*. 2003, 2007 *MEPS*)

Theory

"Bigger is better" mechanism

(Miller *et al*. 1988 *CJFAS*)

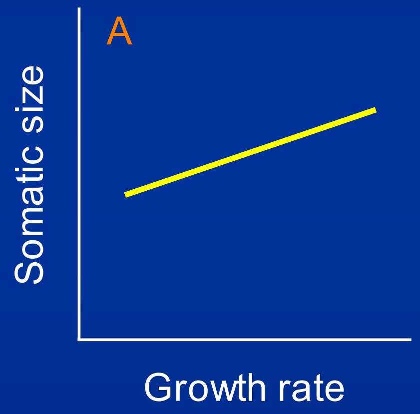
Faster-growing individuals will have a larger somatic size at a given age, which leads to various survival advantages.

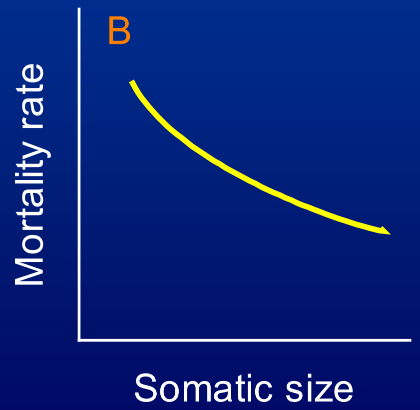
Factor

- Somatic size
- Effect of growth rate: indirect

Operation conditions

1. Positive relationship between growth rate and somatic size at the population level (A)
2. Negative size-selective mortality (B)





Theory

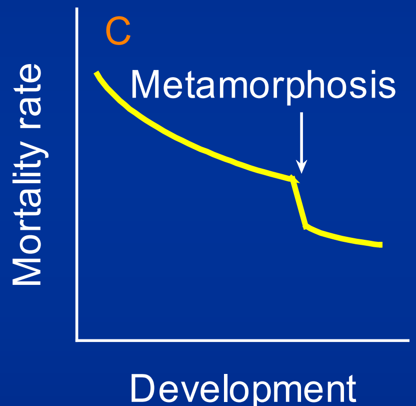
"Stage duration" mechanism

(Chambers & Leggett 1987 *CJFAS*, Houde 1987 *AFSS*)

Faster-growing individuals will experience a much lower cumulative mortality rate during the larval stage.

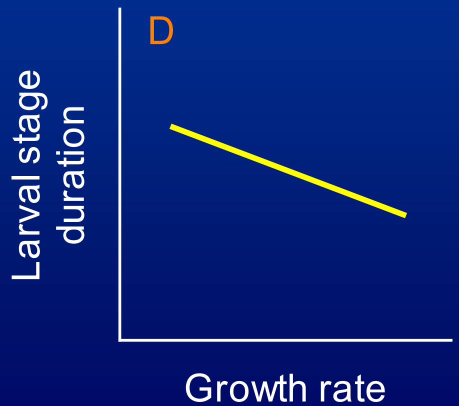
Factor

- Time (stage duration)
- Effect of growth rate: indirect



Operation conditions

1. Larval stage characterized by higher mortality rate (C)
2. Negative relationship between growth rate and larval stage duration (D)



Theory

"Growth-selective predation" mechanism

(Takasuka *et al*. 2003, 2007 *MEPS*)

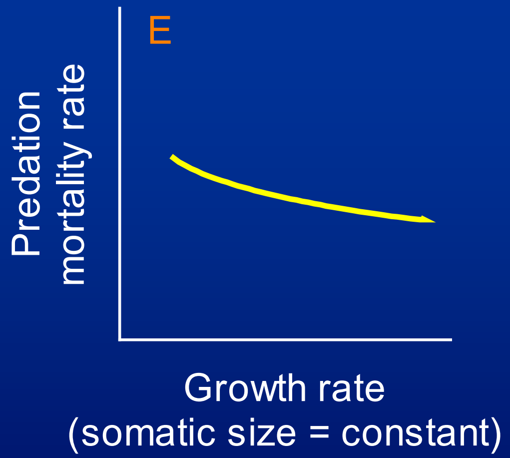
Faster-growing individuals will be less vulnerable to predation mortality than slower-growing conspecifics, even if they are the same size, at a given moment.

Factor

- Growth rate (*per se*)
- Effect of growth rate: direct

Operation conditions

1. Predation mortality
2. Negative growth-selective mortality at a given somatic size (E)



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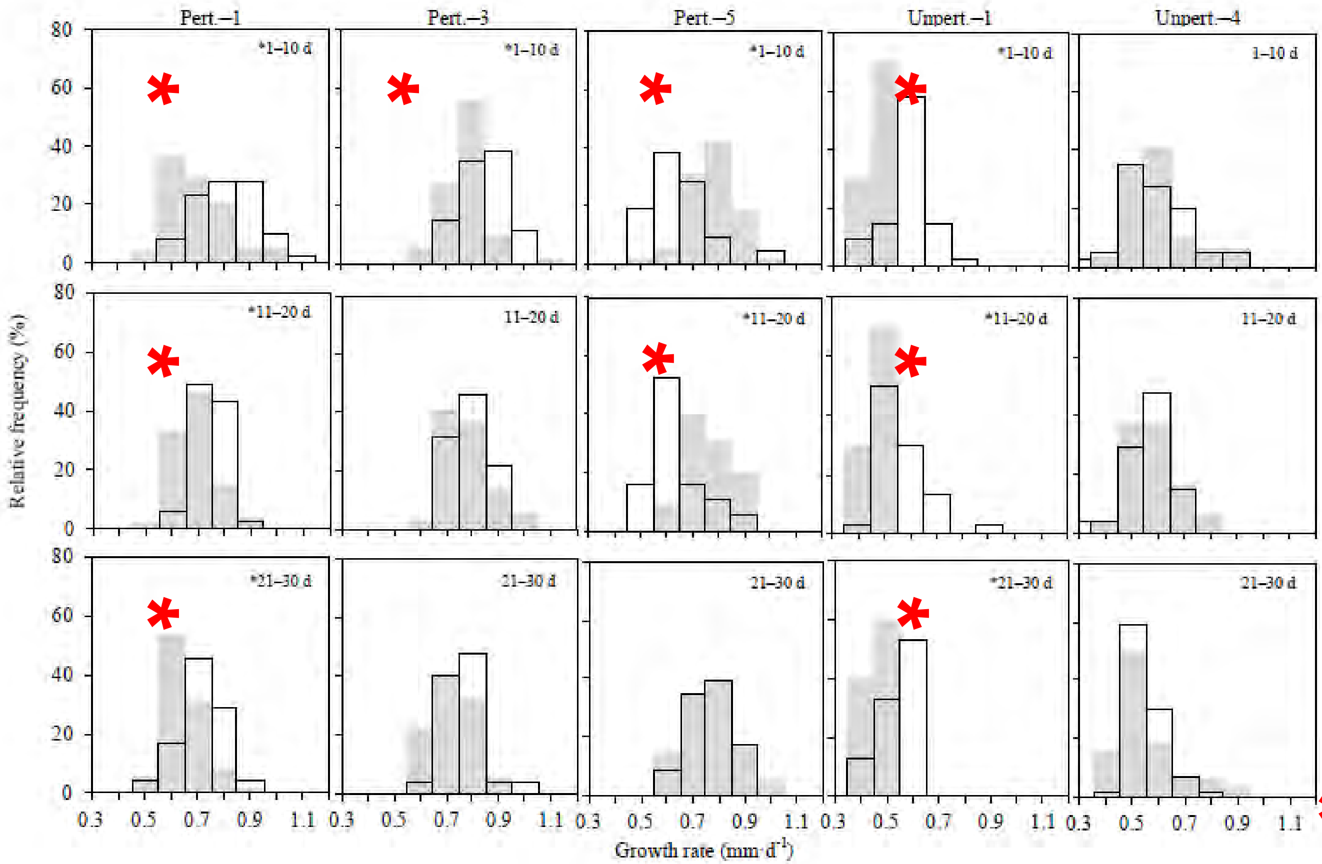
Takasuka *et al*.

Leclerc, V., Sirois, P., Bérubé, P. (2011) *BER*

Advance

Leclerc, V. (2012) PhD thesis

Spatial variability of selective mortality



0-10 d

Original populations

Survivors

11-20 d

21-30 d

* Statistical difference ($p < 0.05$)

Contrary **Contrary** **Supporting** **Contrary** **NS**

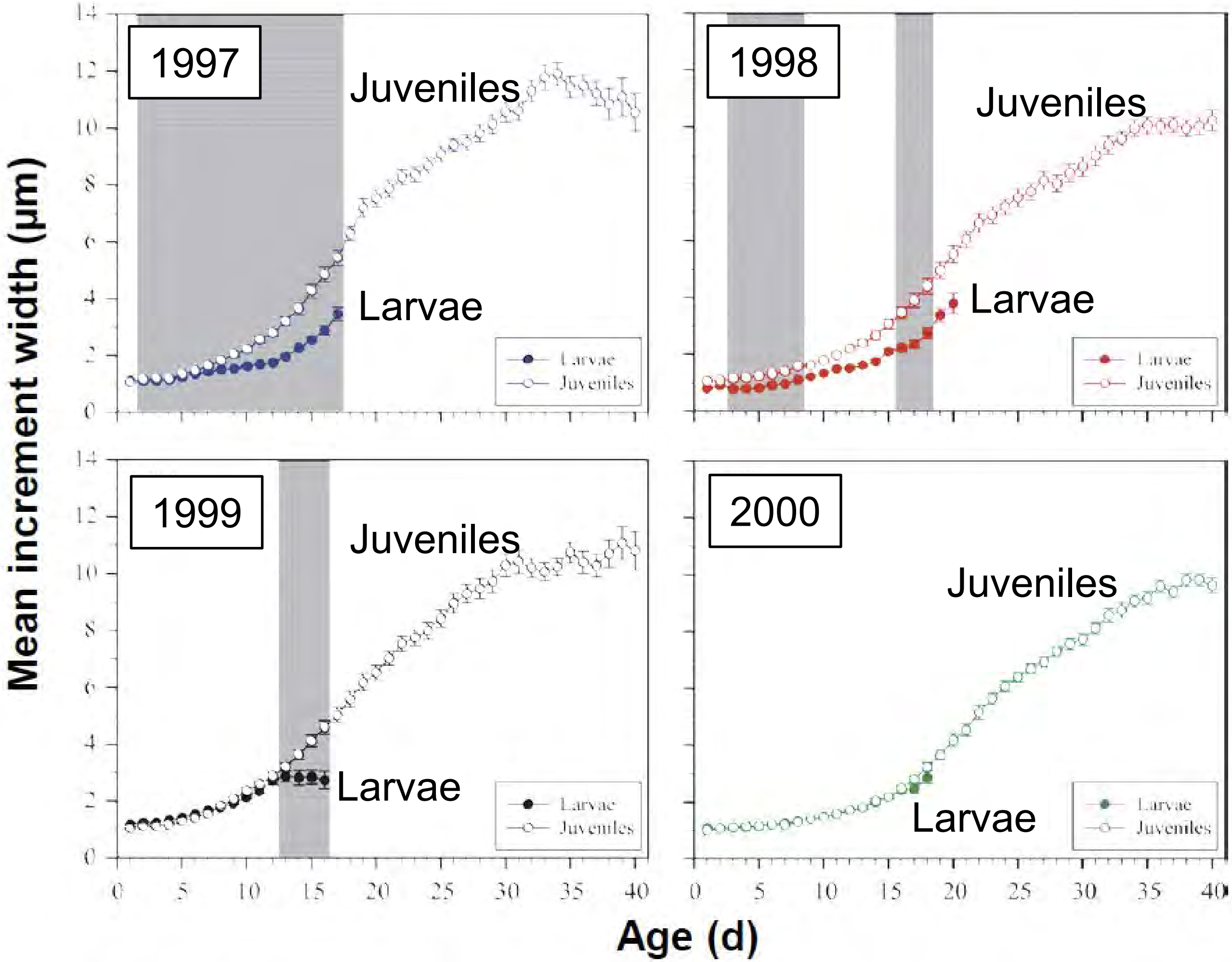
Spatial variability of the direction of selective mortality of yellow perch *Perca flavescens* larvae in perturbed and unperturbed boreal lakes.

Takasuka *et al*.

Advance

Robert *et al*. (2007) *MEPS*

Temporal variability of selective mortality



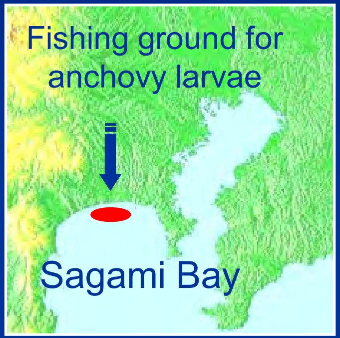
Early growth and recruitment in Atlantic mackerel *Scomber scombrus*: discriminating the effects of fast growth and selection for fast growth.

Advance

Takasuka *et al*. (2003, 2004a,b, 2007) *MEPS*
Robert *et al*. (2010) *FS*

Field sampling

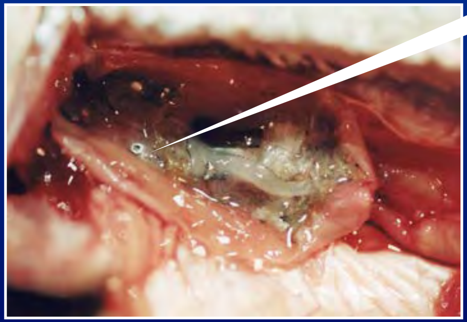
- Japanese anchovy larvae and their predatory fish were captured simultaneously by the same tows of a trawler in a coastal fishing ground and offshore waters.



Growth comparison

Otolith microstructure analysis

Ingested larvae



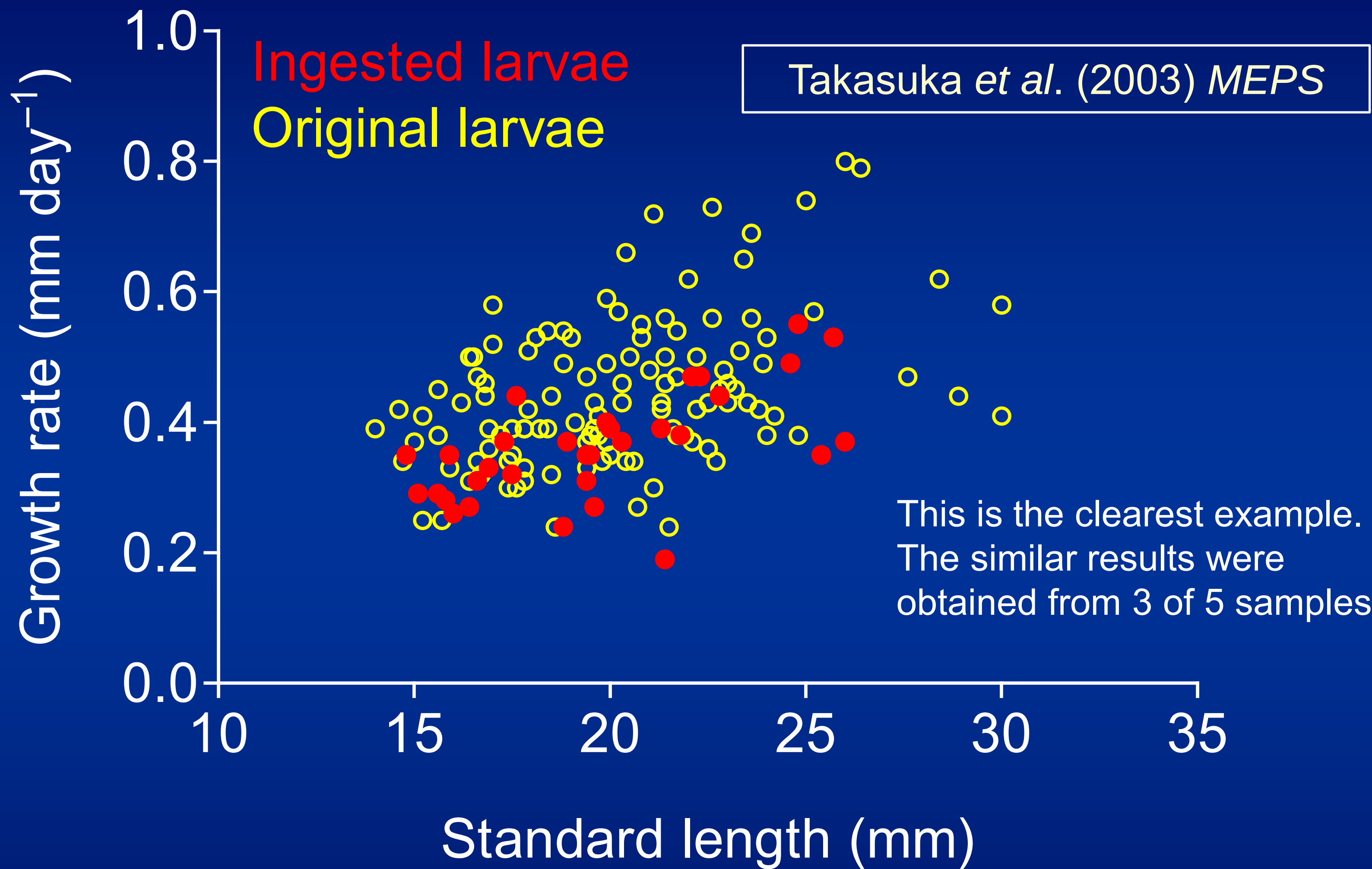
The larvae actually ingested by the predators

Original larvae

The surviving larvae from the original populations

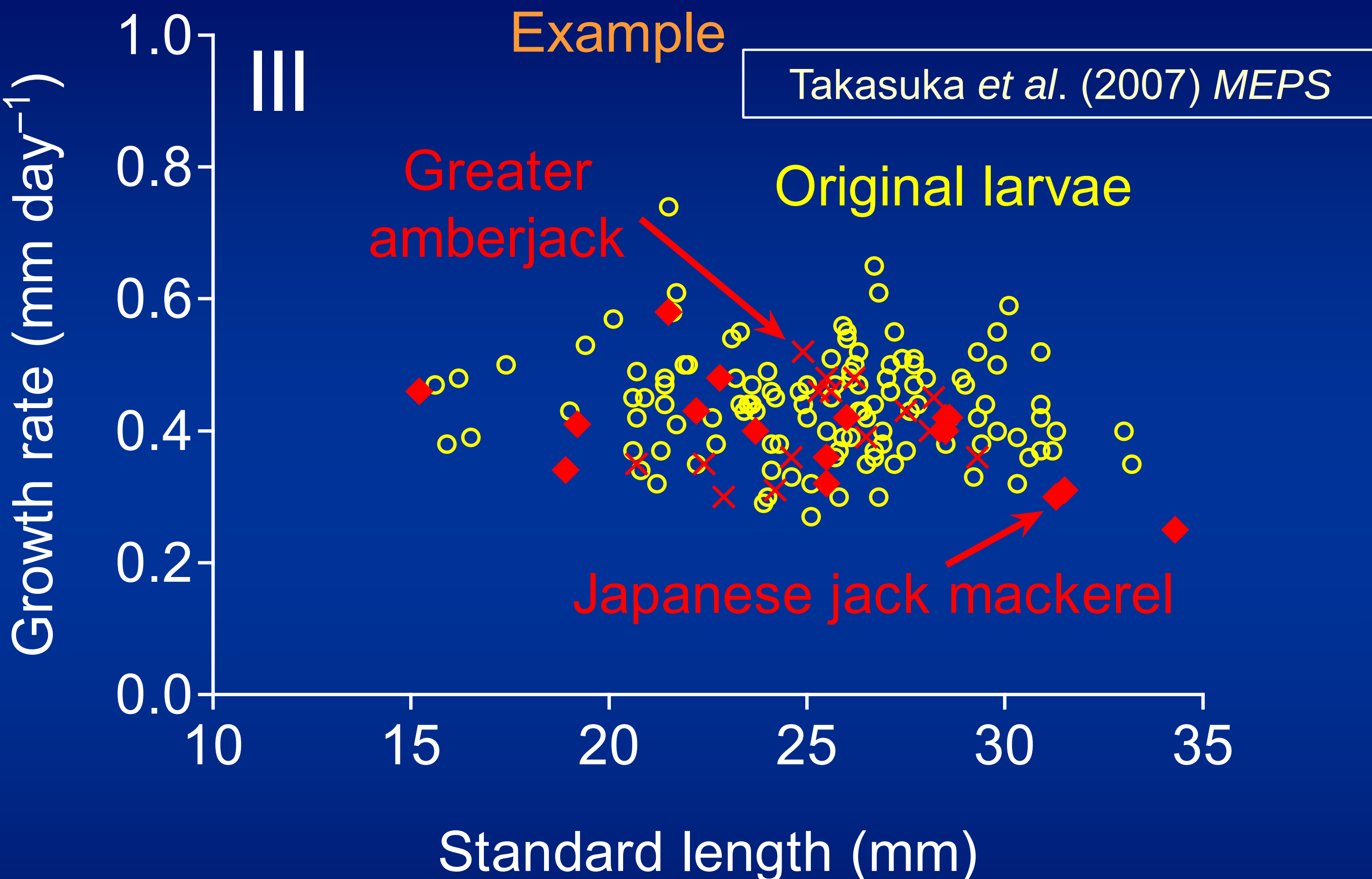
Demonstration of growth-selective predation on anchovy larvae.

Advance



Example of comparison of growth rate on standard length between ingested larvae and original larvae.

Advance



Example of comparison of growth rate on standard length between ingested larvae and original larvae for each predatory species.

Takasuka *et al*.

Advance

Takasuka *et al*. (2007) *MEPS*
Robert *et al*. (2010) *FS*

Growth-selective predator

Japanese anchovy
Engraulis japonicus

Pacific round herring
Etrumeus teres

Japanese jack mackerel
Trachurus japonicus

White croaker
Pennahia argentatus

Non-growth-selective predator

Japanese sea bass
Lateolabrax japonicus

Greater amberjack
Seriola dumerili

Skipjack tuna
Katsuwonus pelamis

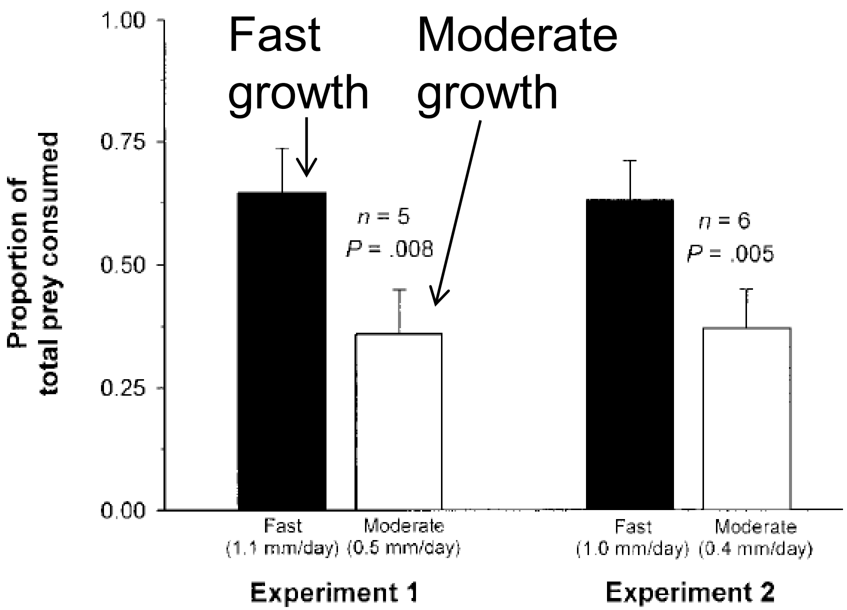
Chub mackerel & Spotted mackerel
Scomber japonicus & S. australasicus

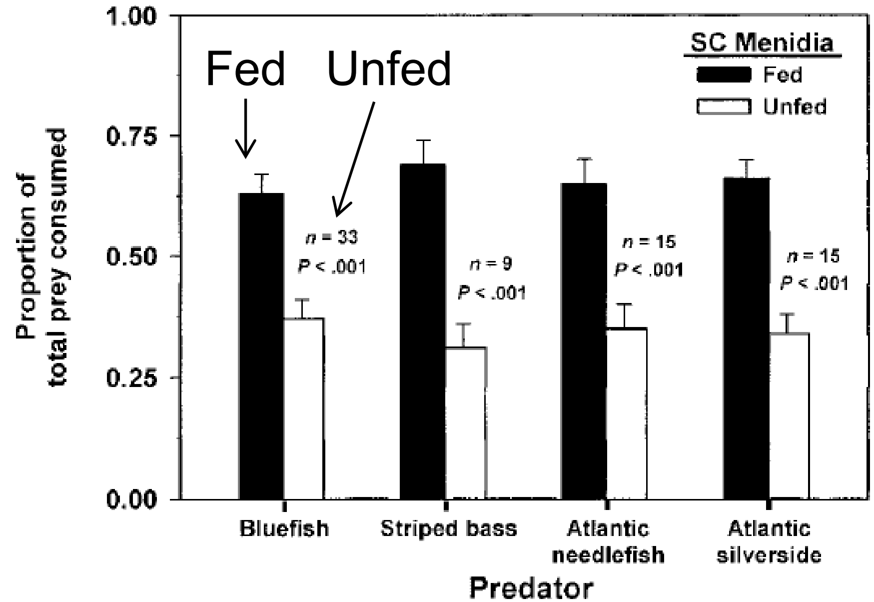
Predator-specific growth-selective predation on anchovy larvae.

Advance

Evidence contrary to GSP from laboratory experiments

Lankford, T. E., Billerbeck, J. M., and Conover, D. O. (2001) Evolution of intrinsic growth and energy acquisition rates. II. Trade-offs with vulnerability to predation in *Menidia menidia*. *Evolution*, 55: 1873–1881.





Fast-growth group was more vulnerable to predation mortality.

Fed group was more vulnerable to predation mortality.

Example of energy trade-off between growth and physiological performance (Lankford *et al*. 2001 *Evolution*)

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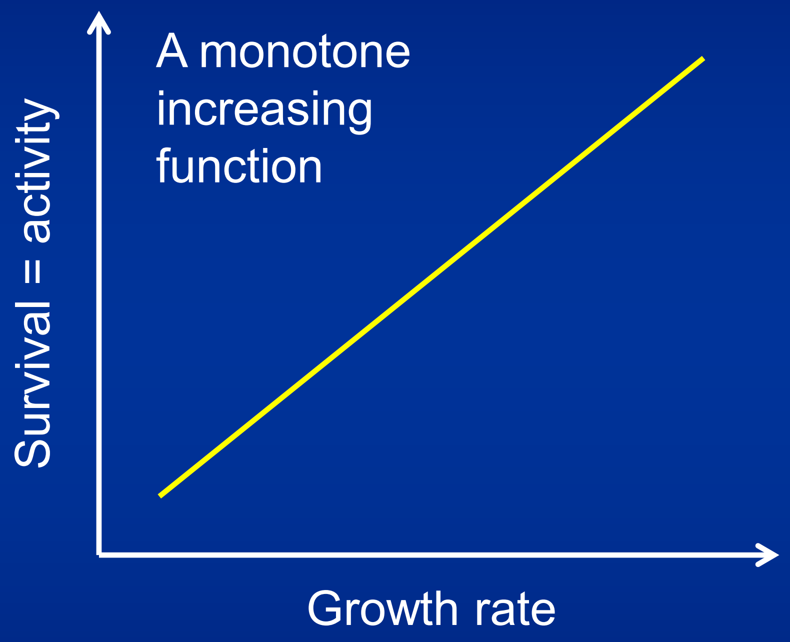
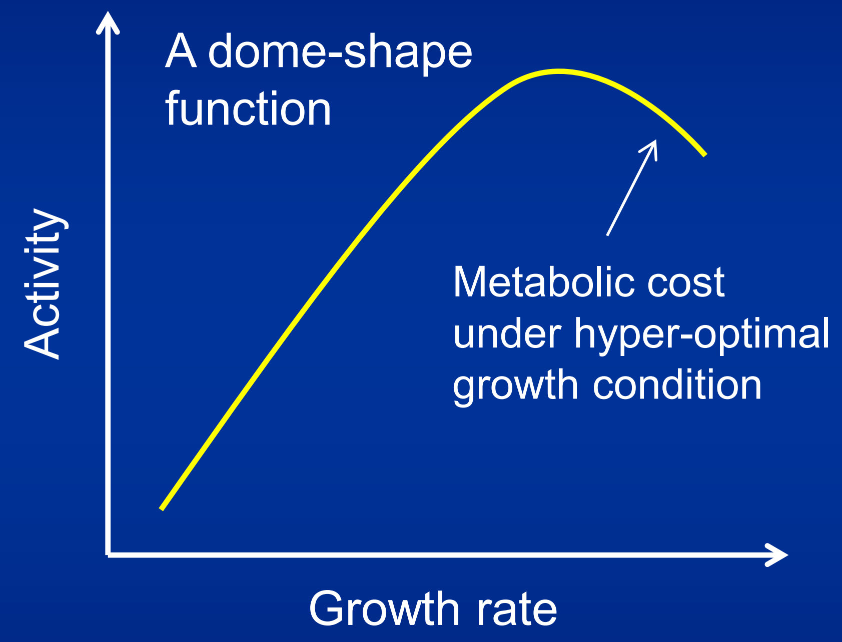
Synthesis

Start point of the conceptual framework

Growth–survival paradigm



Start point of reconstruction



- Energy trade-off between growth and physiological performance (Lankford *et al*. 2001, Munch & Conover 2003 *Evolution*)

Synthesis

Definition of predator type

Predator type	Definition	Example
Filter/ particulate	Fish and invertebrate predators that prey upon zooplankton, ichtyoplankton, or both by filter feeding, particulate feeding, or switching between filter and particulate feeding strategies	Anchovy Sardine Herring Jack mackerel
Raptorial	Fish and invertebrate predators that are strongly piscivorous and exclusively prey upon fish larvae and juveniles by active raptorial feeding strategy	Tuna Mackerel Cod Sea bass
Ambush	Fish and invertebrate predators that prey upon fish larvae and juveniles by ambush raptorial or entangling feeding strategy	Jellyfish Euphausiid Shrimp Ctenophore Hydra

* Predator type: terms for convenience of categorization

Synthesis

Predator type and driving factor for predation

Predator type	Anti-predator behavior (activity)	Energy gain/cost for predator	Encounter rate (activity)
Filter/ particulate	Key	Potential	Potential
Raptorial	Negligible	Key	Negligible
Ambush	Potential	Negligible	Key

Key	Key factor which is considered in the conceptual framework
Potential	Potentially effective factor which is additionally considered
Negligible	Negligible or less effective factor which is not considered

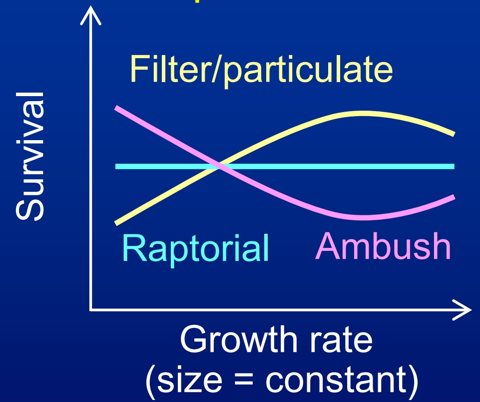
Takasuka *et al*.

Synthesis

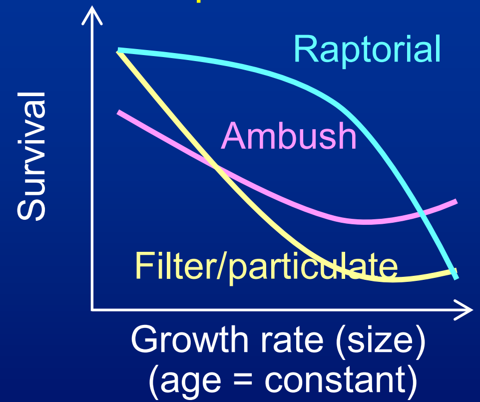
Conceptual curves of growth–survival relationships were constructed for the 3 predator types for the 3 growth–survival mechanisms, respectively.

Predator type	Anti-predator behavior (activity)	Energy gain/cost for predator	Encounter rate (activity)
Filter/particulate	Key	Potential	Potential
Raptorial	Negligible	Key	Negligible
Ambush	Potential	Negligible	Key

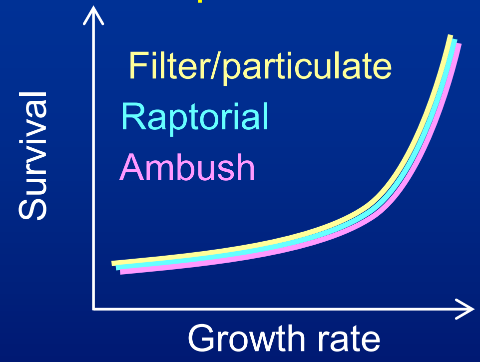
Growth-selective predation



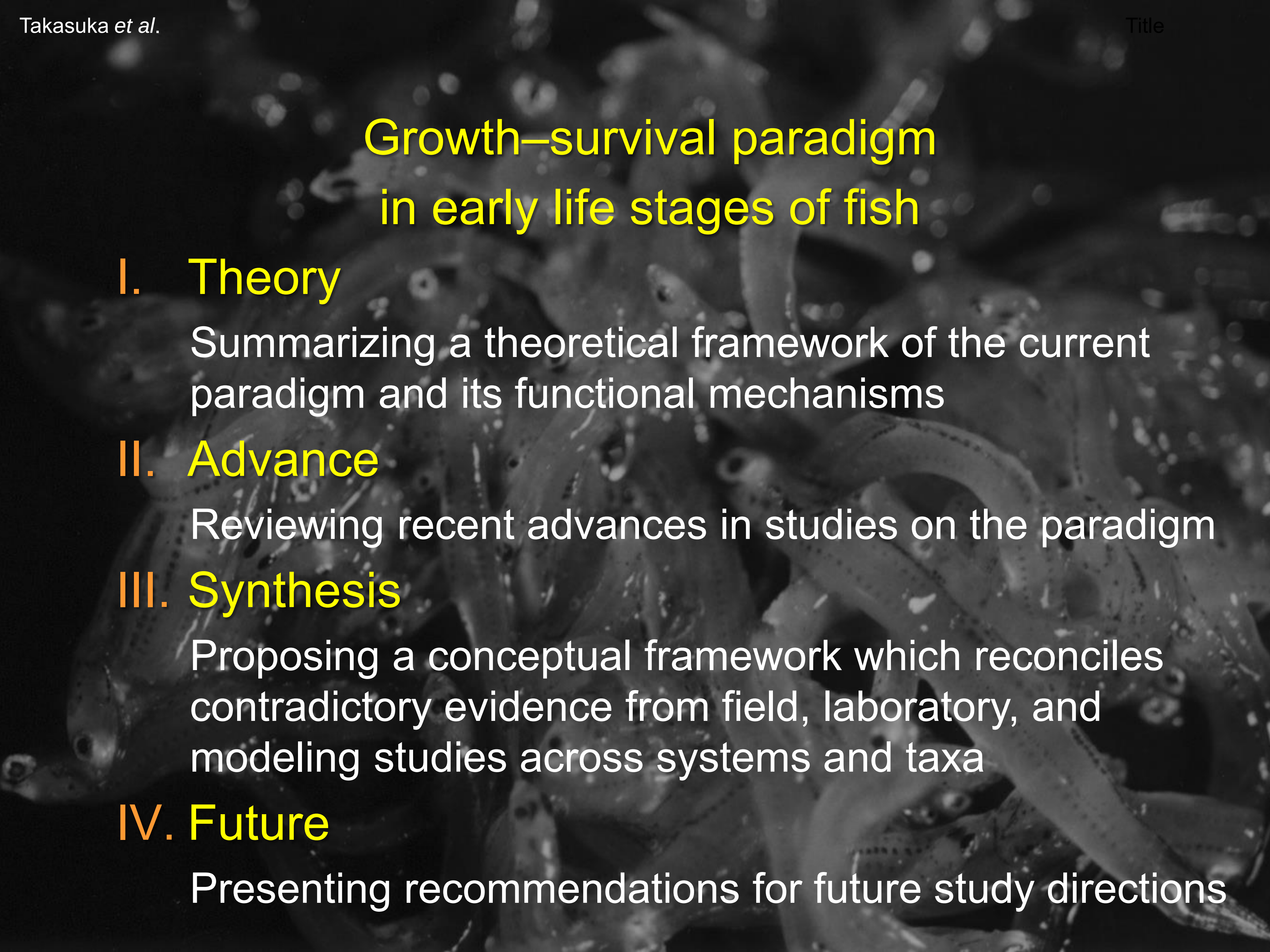
Size-selective predation



Stage-selective predation



Key and potential drivers are considered with optimal foraging theory (energy trade-off) on the side of predators.



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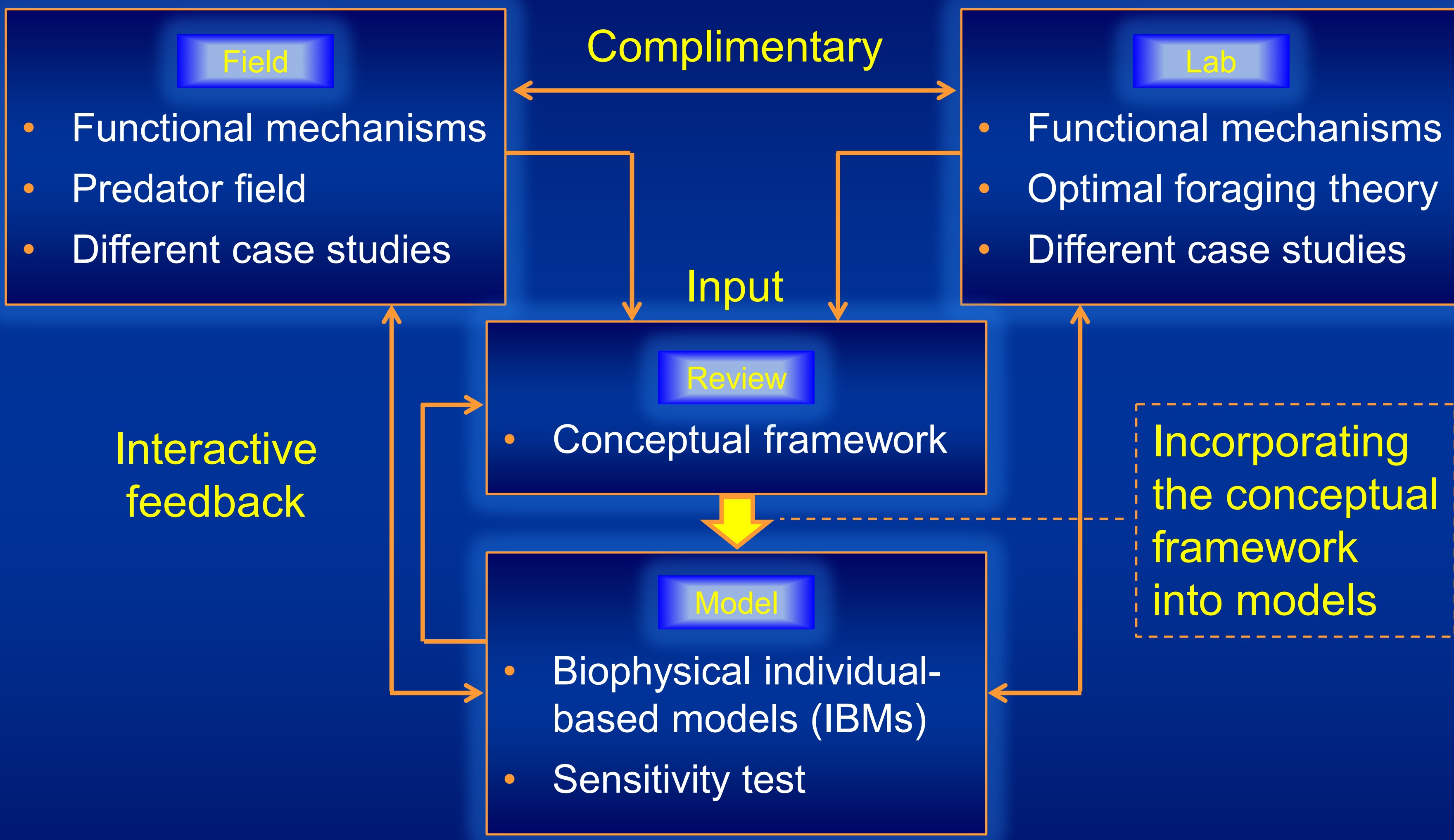
Future

Multidisciplinary approach



How much “realistic”?

Maybe a far-reaching goal, but we wish to start discussion.

Next stage

Next stage

Stage-I (Background)		Stage-II (Symposium)
Japan–Canada collaboration team	→	Scientists from around the world
Common expertise Common perspectives		Different expertise Different perspectives
Proposal		Discussion
“This is what we think.”		“What do you think?”

Symposium on

Growth–survival paradigm in early life stages of fish:

controversy, synthesis, and multidisciplinary approach

November 9–11, 2015

National Research Institute of Fisheries Science, Fisheries Research Agency, Yokohama, Japan

Objectives

1. “Controversy”

   Extracting controversial issues on the paradigm.

2. “Synthesis”

   Proposing ideas for reconciling and synthesizing contradictory results based on different perspectives from different study groups.

3. “Multidisciplinary approach”

   Promoting a collaborative framework for field, laboratory, and modeling studies.

➢ Proposing recommendations for future studies through discussion.

Objectives

Overall goal

To improve our understanding of growth–survival relationships
(“comprehensive”, “synthetic”, and “realistic”)

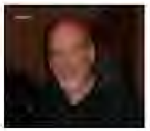
in order to facilitate the prediction of recruitment dynamics through numerical modeling.

Organizers

	Akinori Takasuka (Japan)	National Research Institute of Fisheries Science, Fisheries Research Agency E-mail: takasuka@affrc.go.jp
	Dominique Robert (Canada)	Centre for Fisheries Ecosystems Research, Fisheries and Marine Institute, Memorial University of Newfoundland E-mail: dominique.robert@mi.mun.ca
	Jun Shoji (Japan)	Field Science Education and Research Center, Hiroshima University E-mail: jshoji@hiroshima-u.ac.jp
	Pascal Sirois (Canada)	Research Chair on Exploited Aquatic Species, Department of Fundamental Sciences, University of Quebec at Chicoutimi E-mail: pascal_sirois@uqac.ca

Advisers

The organizers asked two scientists to review progresses of the activities as advisers.

	Louis Fortier (Canada)	Québec-Océan, Département de Biologie, Université Laval E-mail: Louis.Fortier@bio.ulaval.ca
	Yoshioki Oozeki (Japan)	Headquarters, Fisheries Research Agency E-mail: oozeki@affrc.go.jp

PROGRAM

Funding Agencies

日本学術振興会	Japan Society for the Promotion of Science (JSPS) (http://www.jsps.go.jp/english/index.html)
FRA Fisheries Research Agency	Fisheries Research Agency (FRA) (http://www.fra.affrc.go.jp/english/eindex.html)

Research projects

科研費 KAKENHI	Grant-in-Aid for Scientific Research (A) Takasuka, A. (PI), Oozeki, Y., Kuroda, H., Okunishi, T. KAKENHI No. 26252031 (April 2014 to March 2019) (http://kaken.nii.ac.jp/d/p/26252031.en.html)
科研費 KAKENHI	Grant-in-Aid for Scientific Research (B) Shoji, J. (PI), Mitamura, H., Takasuka, A. KAKENHI No. 24380107 (April 2012 to March 2016) (http://kaken.nii.ac.jp/d/p/24380107.en.html)
科研費 KAKENHI	Grant-in-Aid for Scientific Research (C) Oozeki, Y. (PI), Okamura, H., Takasuka, A. KAKENHI No. 26450275 (April 2014 to March 2017) (http://kaken.nii.ac.jp/d/p/26450275.en.html)

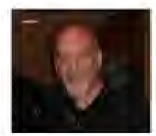
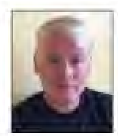
Unique points

- Independency
- Topic focus
- Invited speakers

Keynote speakers

	Pierre Pepin (Canada)	Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada E-mail: pierre.pepin@dfo-mpo.gc.ca
	Arild Folkvord (Norway)	Department of Biology, University of Bergen and the Hjort Centre for Marine Ecosystem Dynamics E-mail: arild.folkvord@uib.no
	Myron A. Peck (Germany)	Institute of Hydrobiology and Fisheries Science, University of Hamburg E-mail: myron.peck@uni-hamburg.de

Invited speakers

	Ignacio A. Catalán (Spain)	Instituto Mediterráneo de Estudios Avanzados (IMEDEA)- Consejo Superior de Investigaciones Cientificas / Universitat de les Illes Balears E-mail: ignacio@imedea.uib-csic.es
	Alberto G. García (Spain)	Coordinator of the Mediterranean Fisheries Program of the Spanish Institute of Oceanography (IEO) E-mail: agarcia@ma.ieo.es
	Marc Hufnagl (Germany)	Institute of Hydrobiology and Fisheries Science, University of Hamburg E-mail: marc.hufnagl@uni-hamburg.de
	Klaus B. Huebert (Germany / USA)	Institute of Hydrobiology and Fisheries Science, University of Hamburg E-mail: klaus.huebert@uni-hamburg.de
	Louis Fortier (Canada)	Québec-Océan, Département de Biologie, Université Laval E-mail: Louis.Fortier@bio.ulaval.ca
	John F. Dower (Canada)	Department of Biology and School of Earth & Ocean Sciences, University of Victoria E-mail: dower@uvic.ca
	Su Sponaugle (USA)	Department of Integrative Biology, Oregon State University E-mail: Su.sponaugle@oregonstate.edu

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	Shin-ichi Ito (Japan)	Atmosphere and Ocean Research Institute, The University of Tokyo E-mail: goito@aori.u-tokyo.ac.jp
	Mikimasa Joh (Japan)	Mariculture Fisheries Research Institute, Hokkaido Research Organization E-mail: joh-mikimasa@hro.or.jp
	Yosuke Tanaka (Japan)	Seikai National Fisheries Research Institute, Fisheries Research Agency E-mail: yosuket@affrc.go.jp
	Motomitsu Takahashi (Japan)	Seikai National Fisheries Research Institute, Fisheries Research Agency E-mail: takahamt@fra.affrc.go.jp


Symposium on
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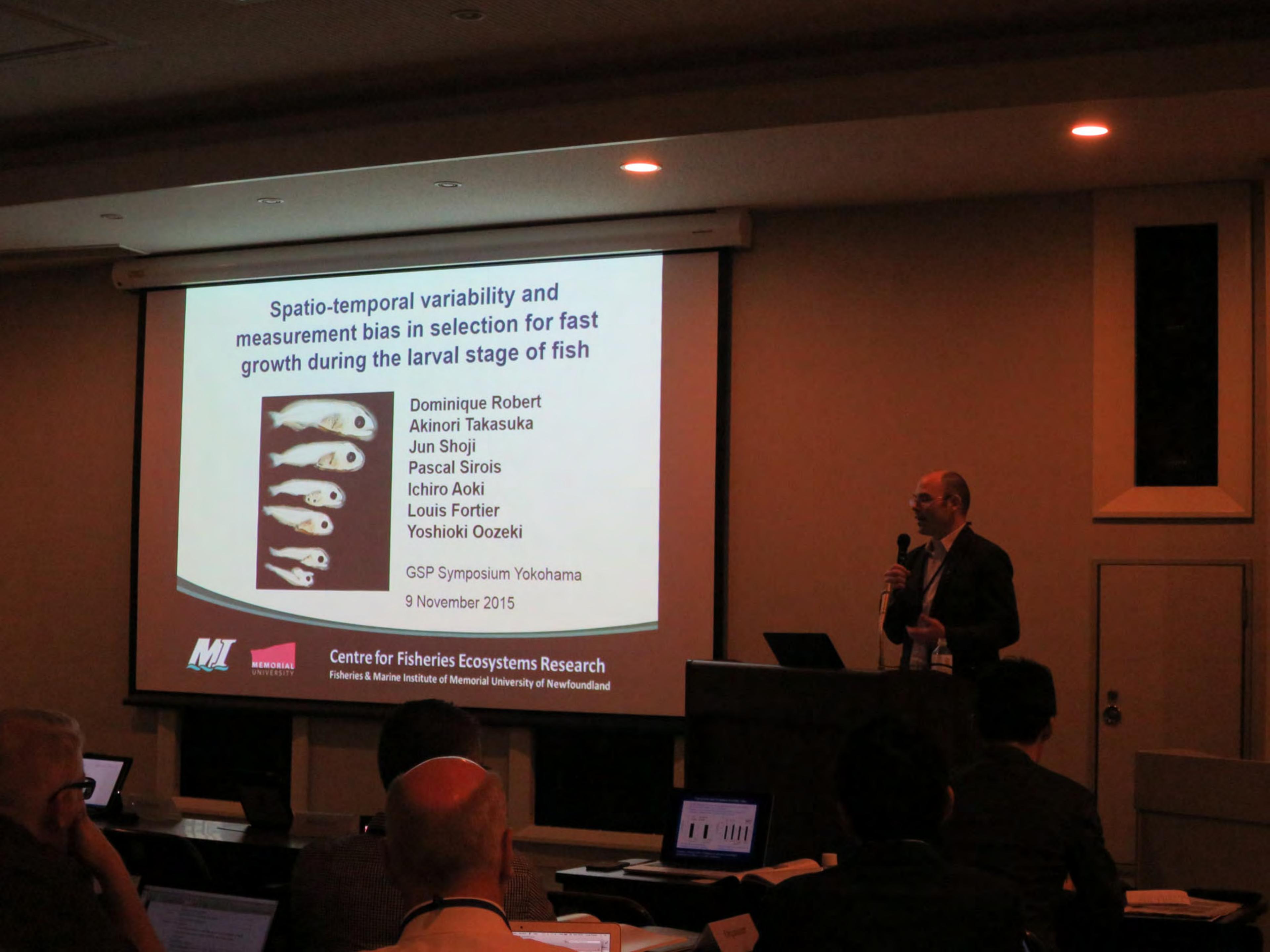
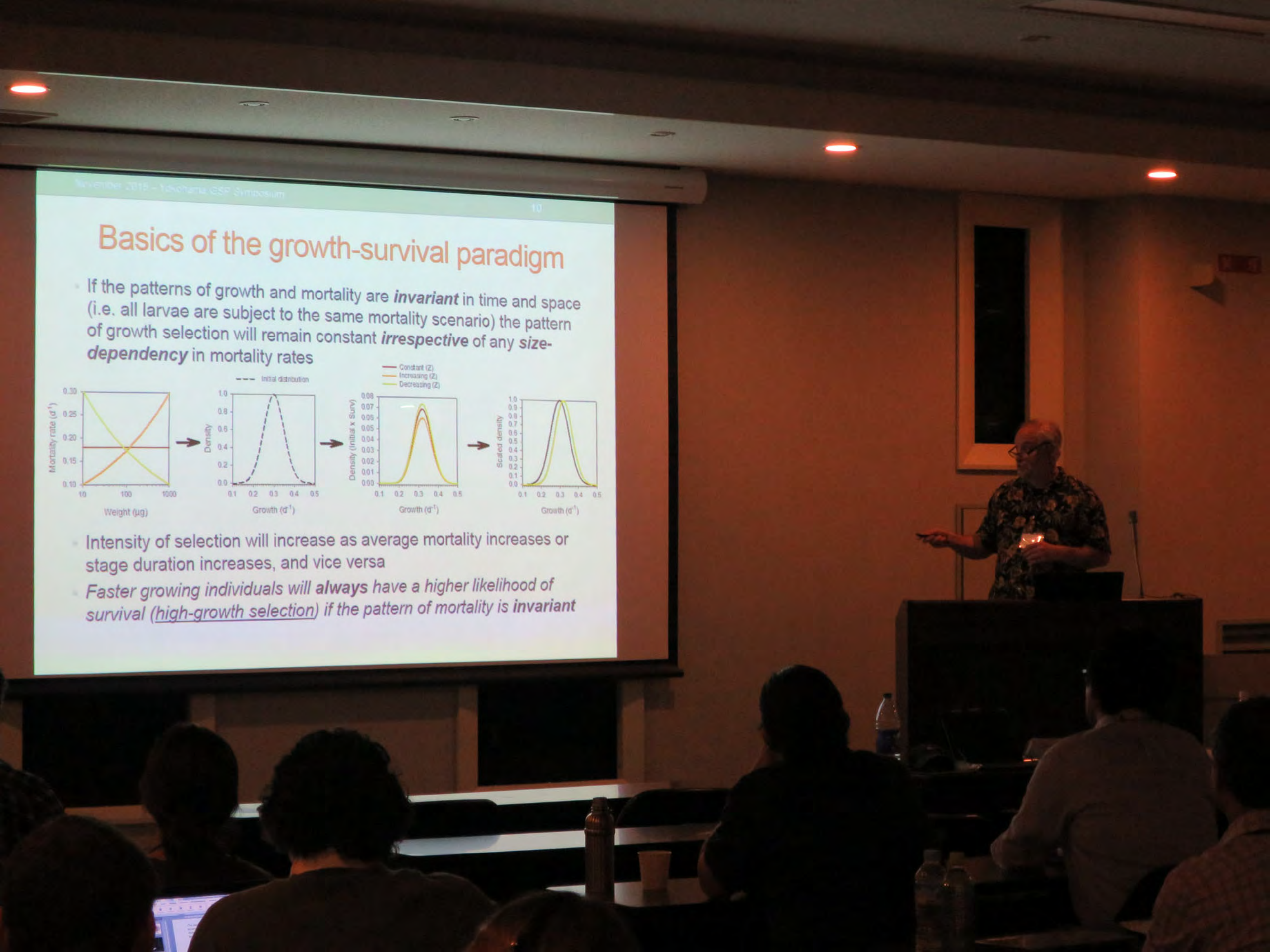
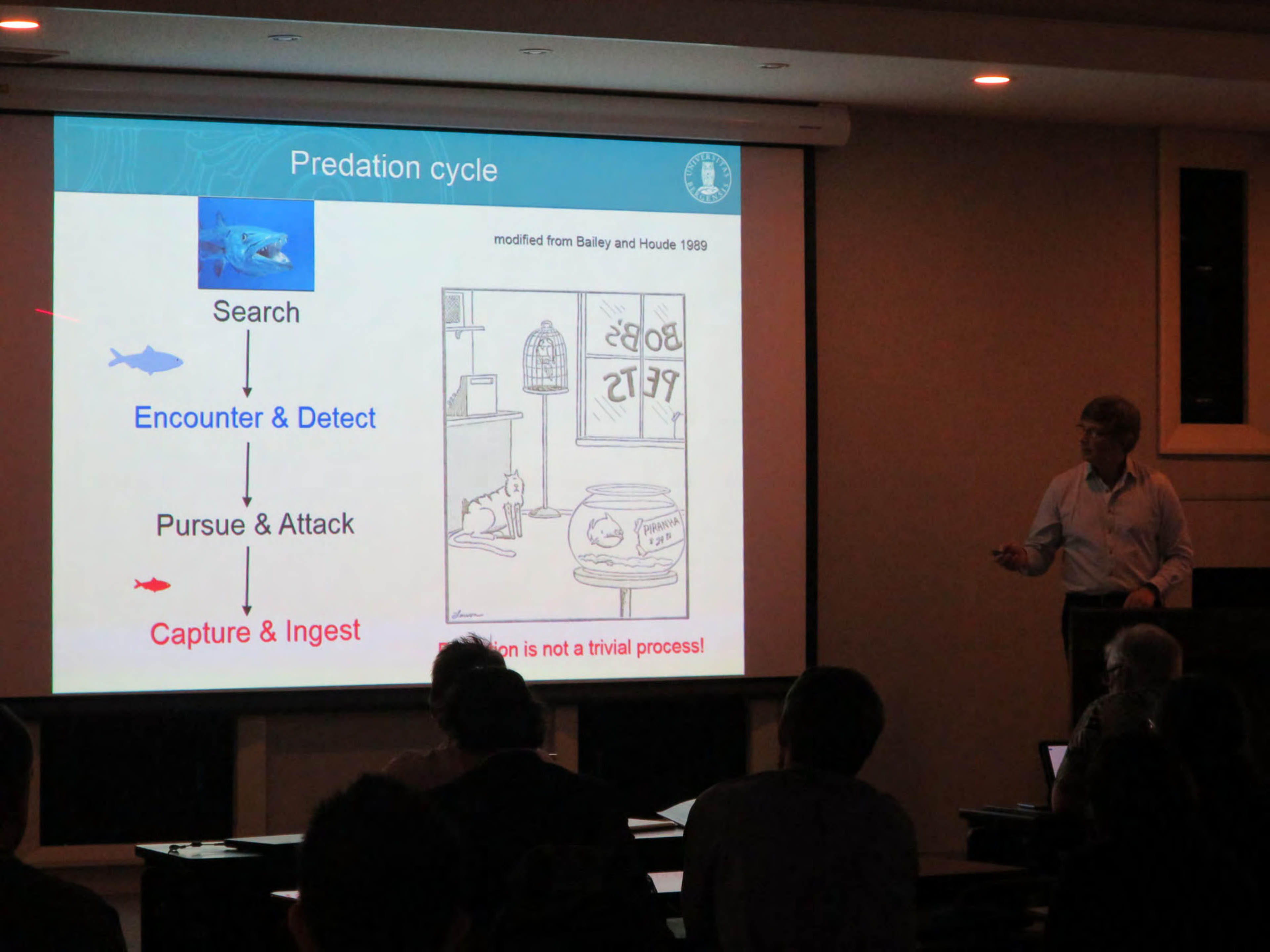
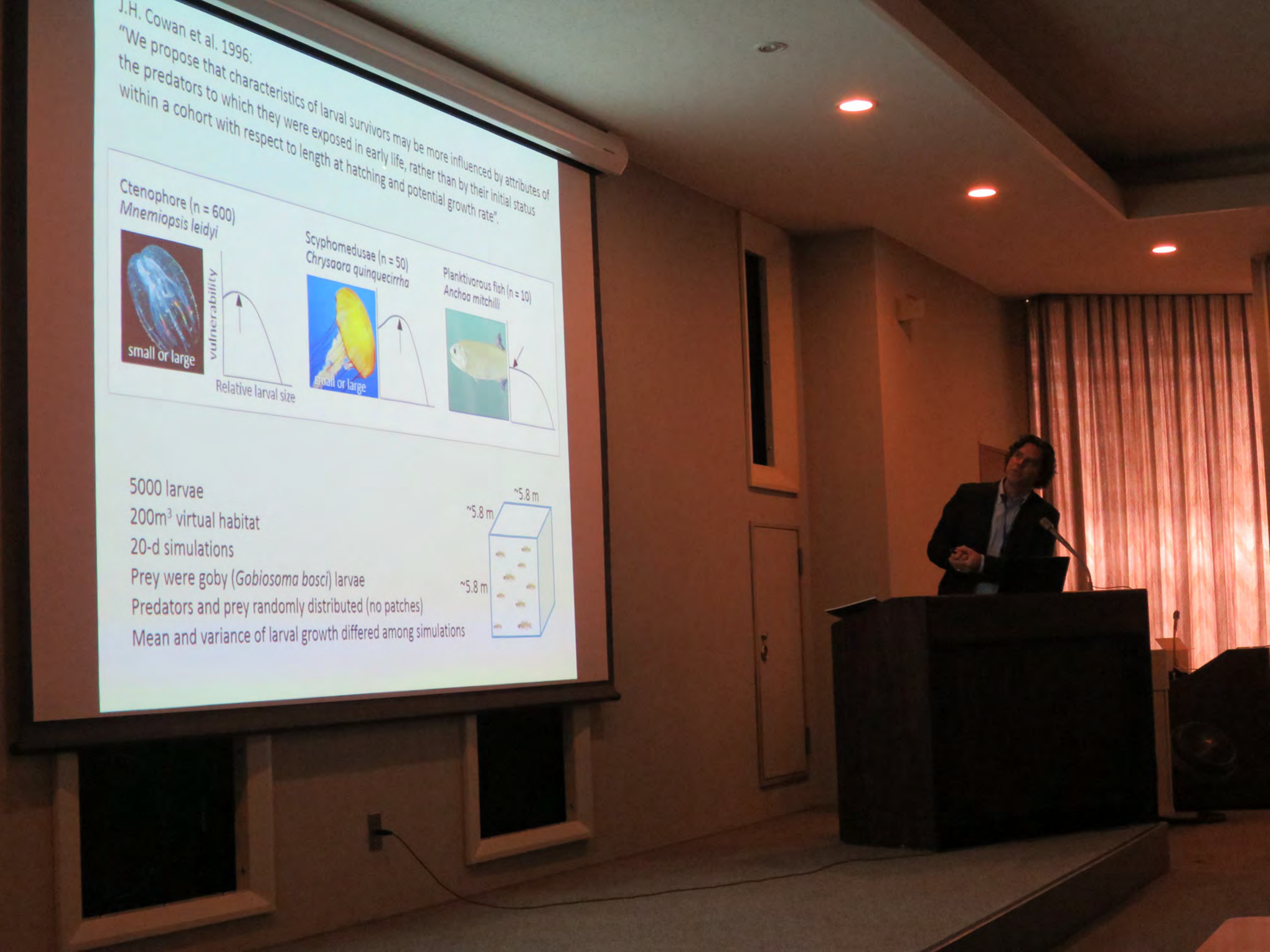

Spatio-temporal variability and measurement bias in selection for fast growth during the larval stage of fish
Dominique Robert
Akinori Takasuka
Jun Shoji
Pascal Sirois
Ichiro Aoki
Louis Fortier
Yoshioki Oozeki
GSP Symposium Yokohama
9 November 2015
MEMORIAL UNIVERSITY
Centre for Fisheries Ecosystems Research
Fisheries & Marine Institute of Memorial University of Newfoundland



Basics of the growth-survival paradigm
If the patterns of growth and mortality are invariant in time and space (i.e. all larvae are subject to the same mortality scenario) the pattern of growth selection will remain constant irrespective of any size-dependency in mortality rates
Initial distribution
Constant (Z)
Increasing (Z)
Decreasing (Z)
Mortality rate (d⁻¹)
Weight (µg)
Density
Growth (d⁻¹)
Density (Initial x Surv)
Scaled density
Intensity of selection will increase as average mortality increases or stage duration increases, and vice versa
Faster growing individuals will always have a higher likelihood of survival (high-growth selection) if the pattern of mortality is invariant



Predation cycle
modified from Bailey and Houde 1989
Search
Encounter & Detect
Pursue & Attack
Capture & Ingest
PIRANHA
ion is not a trivial process!


J.H. Cowan et al. 1996:
"We propose that characteristics of larval survivors may be more influenced by attributes of the predators to which they were exposed in early life, rather than by their initial status within a cohort with respect to length at hatching and potential growth rate".
Ctenophore (n = 600)
Mnemiopsis leidyi
small or large
vulnerability
Relative larval size
Scyphomedusae (n = 50)
Chrysaora quinquecirrha
small or large
Planktivorous fish (n = 10)
Anchoa mitchilli
5000 larvae
200m³ virtual habitat
20-d simulations
Prey were goby (Gobiosoma bosci) larvae
Predators and prey randomly distributed (no patches)
Mean and variance of larval growth differed among simulations
~5.8 m
~5.8 m
~5.8 m

Spatially-explicit biophysical models of the growth and survival of early life stages of fish: A synthesis with recommendations

Myron A. Peck, Marc Hufnagl, Klaus Huebert, Marta Moyano

Ute Daewel
Uni Bergen

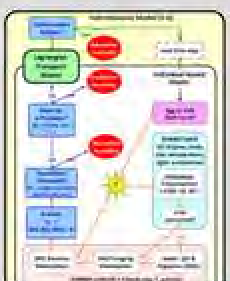
Marc Hufnagl

Markus Kreus

Klaus Hubert

Anna Akimova
Thünen Institute

Marta Moyano



GSP Symposium, Yokohama, November 11th, 2015

Yokohama 11/2015
growth-survival
paradigms in
e.l.s. of fish

When and how do growth paradigms evolve from IBMs and size-structured models?

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Growth-survival problems in a coupled model between fish-growth and environments

Shin-ichi Ito (Univ. Tokyo)
Takeshi Okunishi (TNFRI, FRA)
Michio Yoneda (NRIFEIS, FRA)
Kosei Komatsu (Univ. Tokyo)
Tatsuya Sakamoto (Univ. Tokyo)
Akinori Takasuka (NRIFS, FRA)
Sachihiko Itoh (Univ. Tokyo)

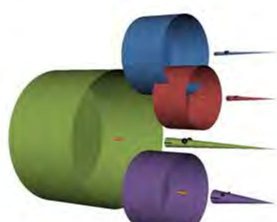
Today's contents

1. backgrounds
2. model developments
3. hindcast simulatoin on larval growth
4. hindcast simulation on survival rate
5. future perspectives

Modeling larval fish growth using Quirks

Klaus B. Huebert[1,2], Johannes Pätsch[1], Marc Hufnagl[1], Markus Kreus[1], and Myron A. Peck[1]

[1]University of Hamburg, Germany
[2] Chesapeake Biological Laboratory, USA



IMEDEA

"Are management goals impeding or fostering the scientific progress of the growth-survival paradigm?"

Ignacio A. Catalán

IMEDEA (Instituto Mediterráneo de Estudios Avanzados: Spanish National Research Council (CSIC)-University of the Balearic Islands (UIB)

www.fishecology.es

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Symposium on
Growth–survival paradigm
in early life stages of fish
禁煙
禁煙
禁煙

Workshop

A post-symposium workshop

(November 12–13)

A total of 30 invited participants

Objectives

1. Providing a networking environment for future collaborations among the participants to resolve some important issues identified during the symposium/workshop.
2. Publishing a “perspective” paper co-authored by all workshop participants to identify what is needed for breakthroughs. The paper will provide concrete study designs to improve our understanding of the growth–survival relationships during early life stages of fish.


禁 煙


Organizer

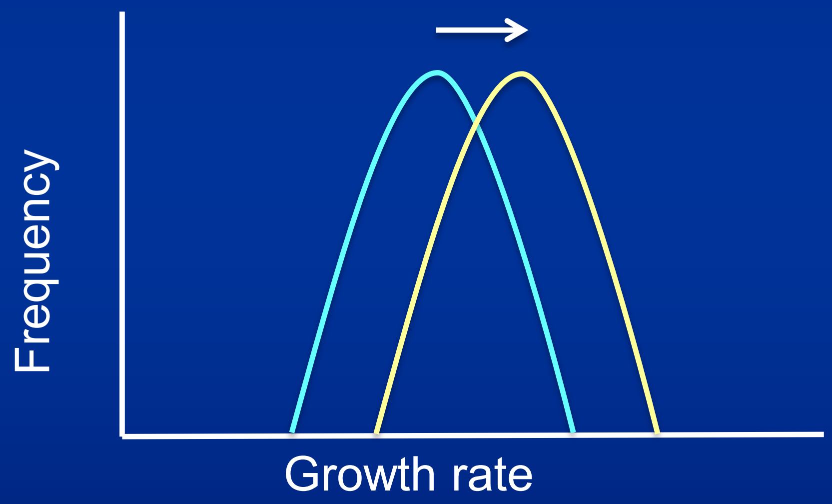

禁煙
NO SMOKING
PLUS
Pop A
CORN CHOCOLATE

Synthesis

Conceptual framework based on growth rate distribution shift

Random survival

Effect of stage duration
Shift to positive direction
(automatically)

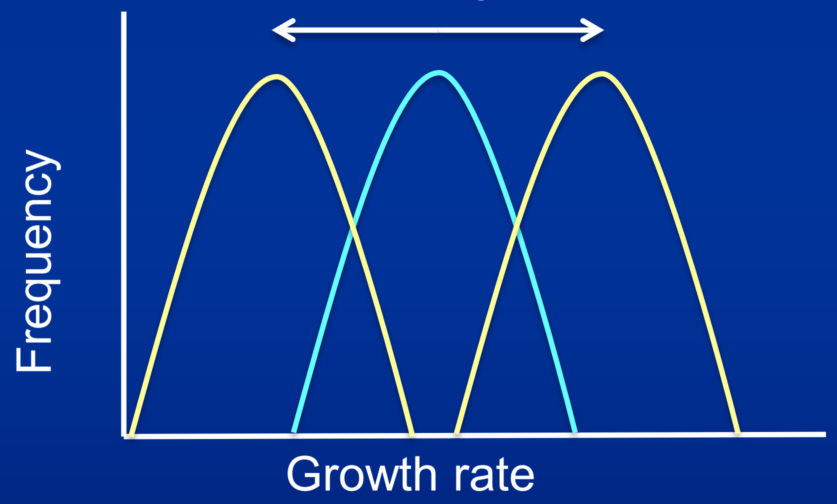


Original populations

Survivors (endpoint)

Growth/size-selective survival

Effect of stage duration
Shift to positive direction
Effect of growth/size selection
Shift to positive or negative direction



Original populations

Survivors (endpoint)

- Dealing with the 3 growth–survival mechanisms in the same framework.
- Quantifying direction and intensity of selection by mean and variance.

List of issues

A total of 83 original issues were summarized into 19 issues under 5 topic categories.

1. Predation mortality
   - Identification of predator field
   - Quantification of predator field
   - Size structure and prey selectivity of predators
   - Refuge availability
   - Predation risk behavior
   - Predation mechanisms

2. Endpoint
   - Size- and/or age-based endpoint
   - Carry-over effects

3. Spatial/temporal scales
   - Representativeness of sampling
   - Spatial and temporal replication

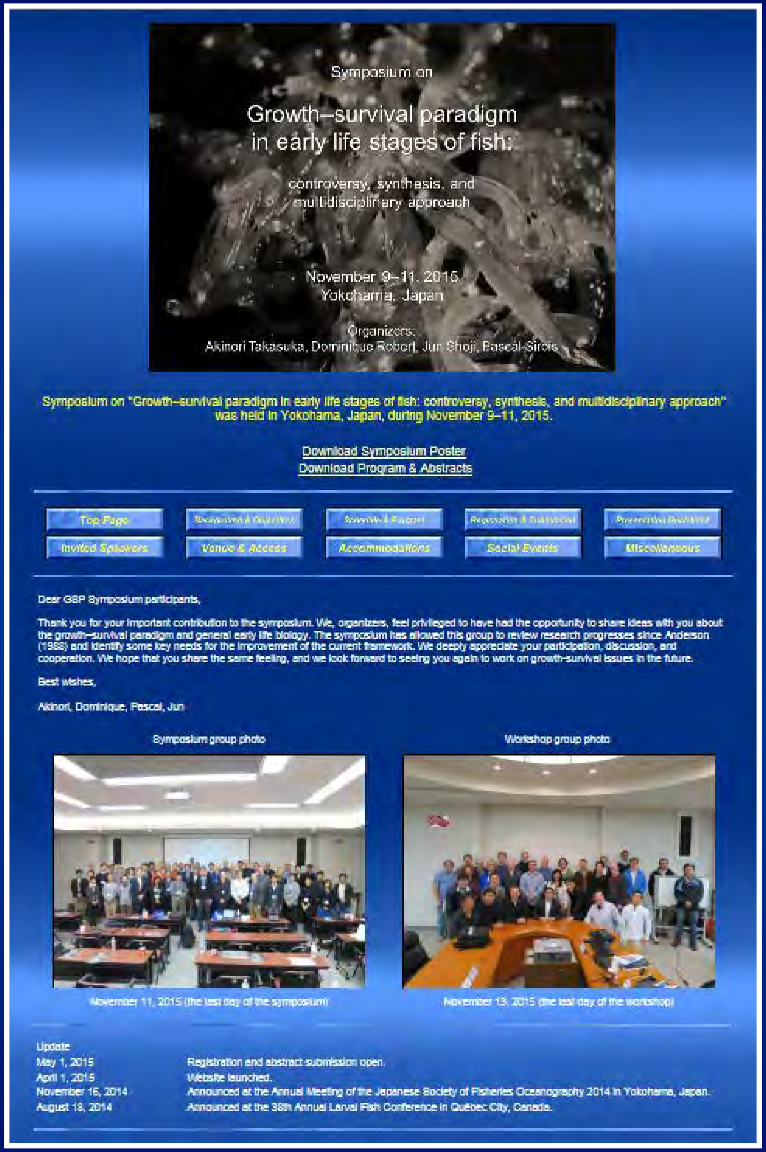
4. Intrinsic factors
   - Maternal effects
   - Genetic selection
   - Behavior repertoire
   - Growth and physiology
   - Stage development

5. Miscellaneous
   - Environmental effects on growth
   - Mortality estimation
   - Reconciling and synthesizing contradictory results from paradigm tests

Concrete study designs (“recipes”) are being prepared for each issue by the group.


NO SMOKING
EPSON

Manuscripts in preparation



1. **"Report"**
   Report of symposium/workshop
2. **"Concept" paper**
   Proposing a new conceptual framework based on growth rate distribution shift
3. **"Recipe" paper**
   Providing concrete study designs for the issues identified for future breakthroughs

http://cse.fra.affrc.go.jp/takasuka/gsp/

Requested issues

- Examples of prey–predator interactions related to behaviors of larvae and predators.
- What is a consequence of growth variability of larvae in the shoals?
- What can happen when larval shoals encounter predators.
- Examples from our previous studies on Japanese anchovy larvae.

Advance

Takasuka *et al*. (2007) *MEPS*
Robert *et al*. (2010) *FS*

Growth-selective predator

Japanese anchovy
Engraulis japonicus

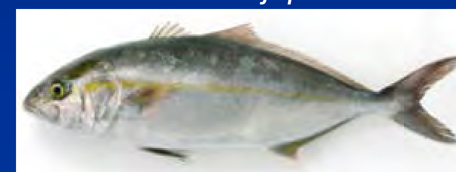
Pacific round herring
Etrumeus teres

Japanese jack mackerel
Trachurus japonicus

White croaker
Pennahia argentatus

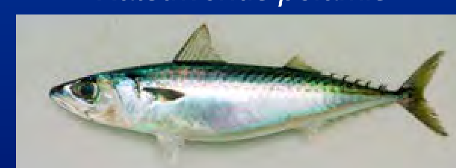
Non-growth-selective predator

Japanese sea bass
Lateolabrax japonicus



Greater amberjack
Seriola dumerili

Skipjack tuna
Katsuwonus pelamis



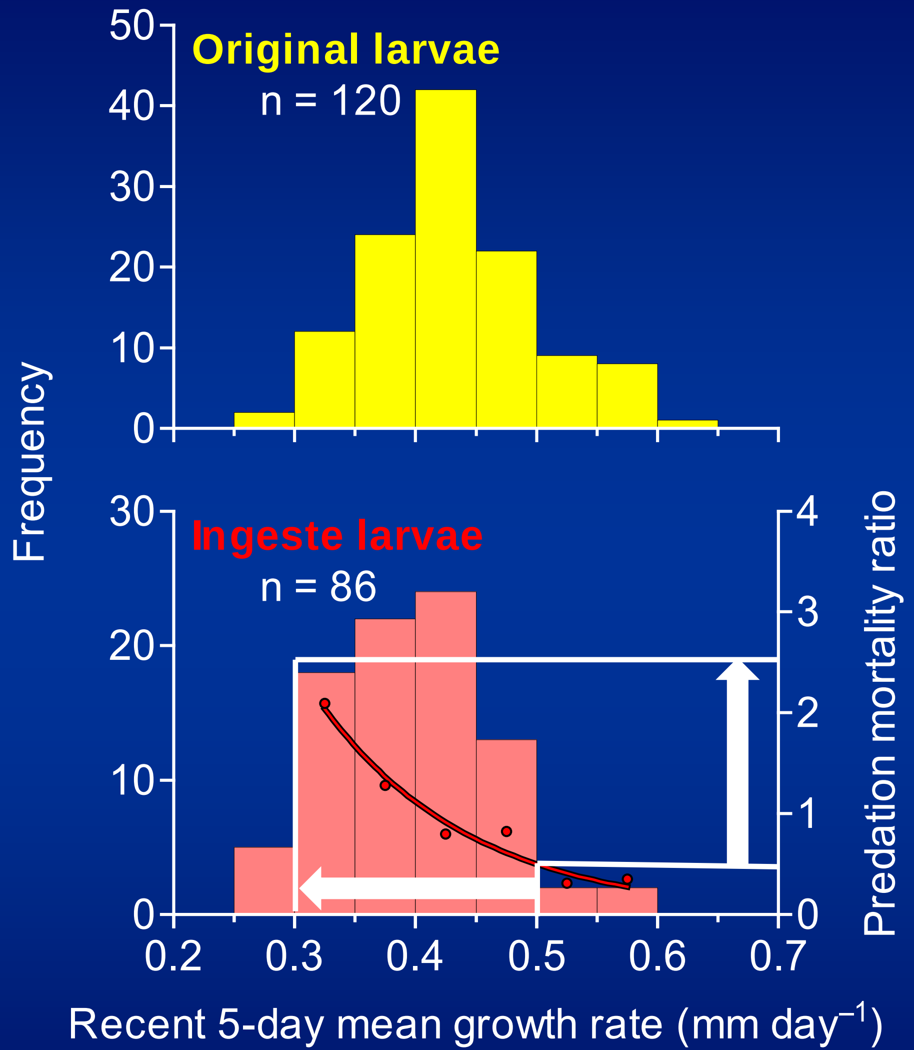
Chub mackerel & Spotted mackerel
Scomber japonicus & S. australasicus

Predator-specific growth-selective predation on anchovy larvae.

Relative predation mortality

Takasuka *et al*. (2007) *MEPS*

Predators:
Pacific round herring
Japanese jack mackerel



Growth decline:
0.20 mm day^{-1}
(0.50 to 0.30 mm day^{-1})

↓

Predation mortality ratio increased from 0.5 to 2.5

↓

<u>Instantaneous</u> predation mortality multiplied by *ca*. 5 times

Frequency distributions of growth rate compared between ingested larvae and original larvae with an index of relative predation mortality.

Advance

Takasuka *et al*. (2007) *MEPS*
Robert *et al*. (2010) *FS*

Growth-selective predator

Japanese anchovy
Engraulis japonicus

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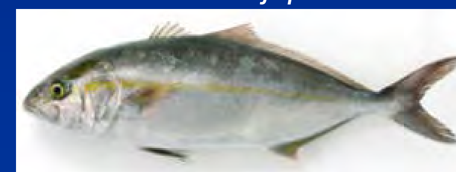

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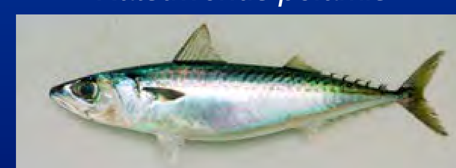


Chub mackerel & Spotted mackerel
Scomber japonicus & S. australasicus

Predator-specific growth-selective predation on anchovy larvae.

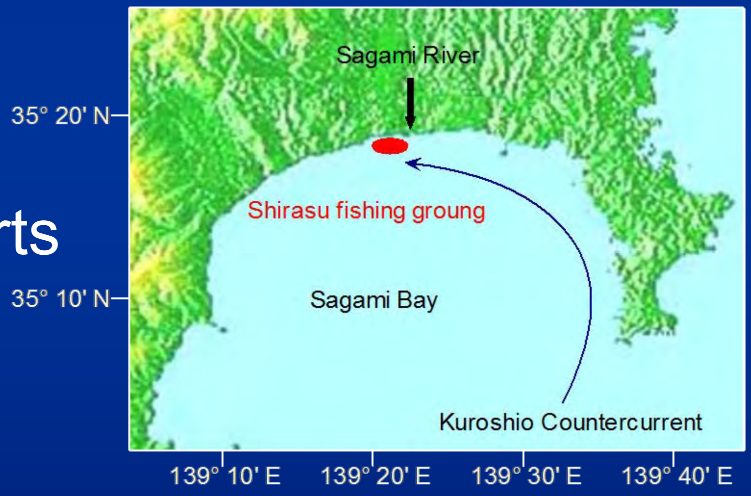
Dynamics

Takasuka *et al*. (2017) *CJFAS*

- What is a consequence of cumulative survival probability when larval shoals encounter different predators?
- Dynamics of growth-based survival mechanisms.

Field sampling

- Anchovy larvae were sampled repeatedly with an interval of *ca*. 2 weeks from multiple cohorts in a coastal fishing ground.



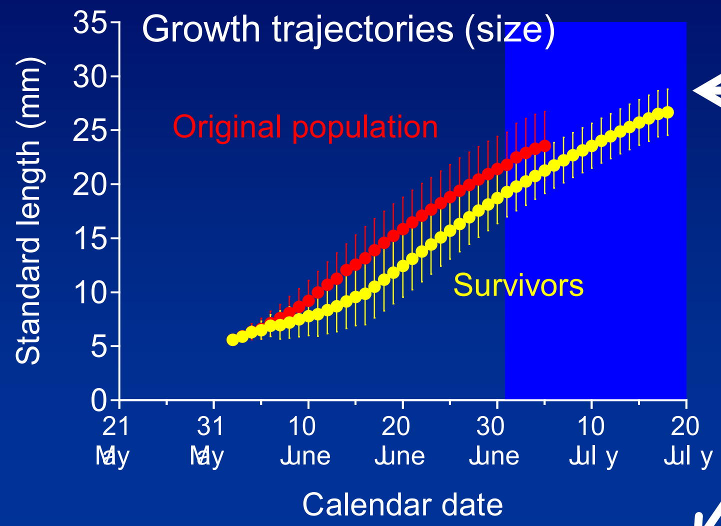
Samples

- The larvae collected at the first sampling: original population
- The larvae collected at the later sampling: survivors

Takasuka *et al.*

Mechanism tests

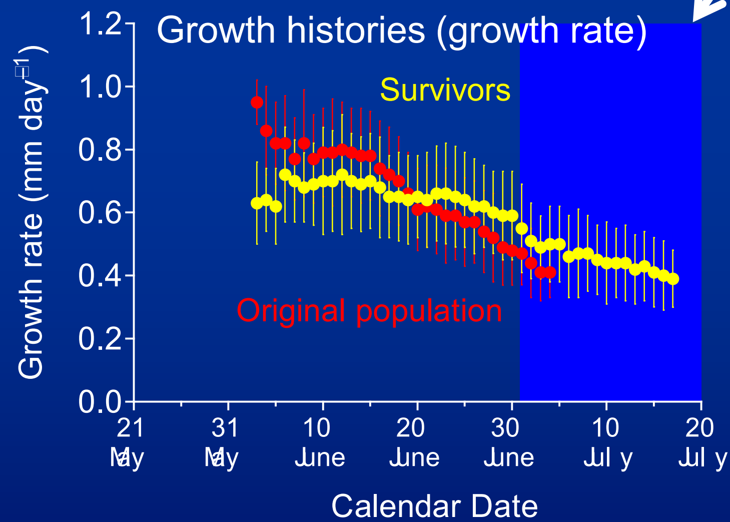
Takasuka *et al.* (2017) *CJFAS*

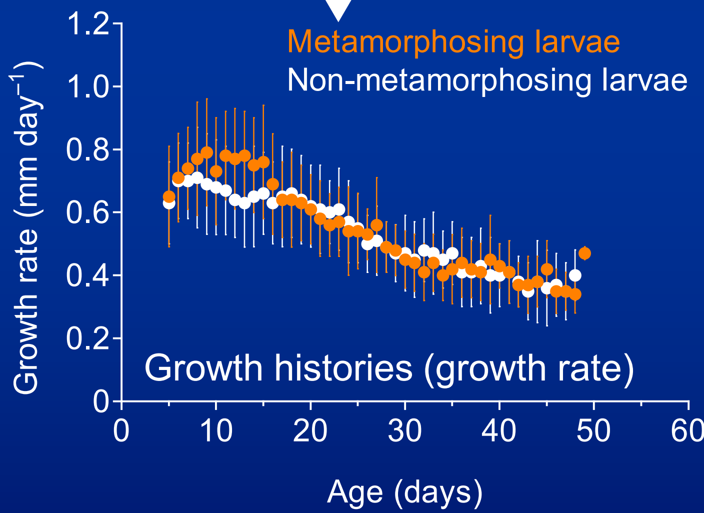


"Bigger is better" test

"Growth-selective predation" test

"Stage duration" test





Three mechanisms tested based on the characteristics of the survivors vs the original population for multiple cohorts.

Takasuka *et al.*

Mechanism tests

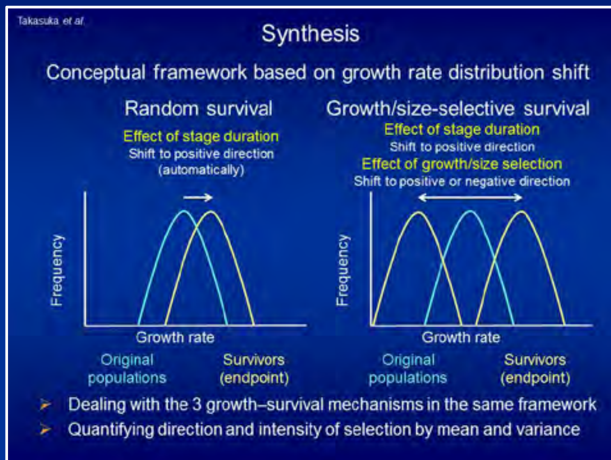
Takasuka *et al.* (2017) *CJFAS*

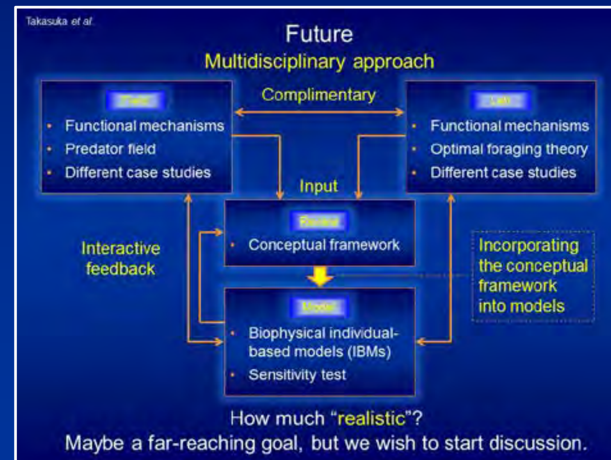
Summary of the test results of the 3 functional mechanisms for the short-term survival processes of multiple cohorts (9 seasonal cohorts & 18 pairs of SV and OP).

Sample	Cohort	Pair		Survival	**Bigger is better**	**Growth-selective**	**Stage duration**
	Season and year	Original	Survivors	period (d)		**predation**	
A	Autumn 2003	OP	SV-1	10	**NS**	**NS**	–
		OP	SV-2	20	**NS**	**NS**	–
		SV-1	SV-2	10	**NS**	**Effective**	–
B	Spring 2004	OP	SV-1	12	**Contrary**	**Effective**	**Effective**
		OP	SV-2	18	**Contrary**	**NS**	–
		SV-1	SV-2	6	**NS**	**Contrary**	–
C	Summer 2004	OP	SV	11	**NS**	**NS**	–
D	Autumn 2004	OP	SV	7	**Contrary**	**Effective**	–
E	Winter 2004	OP	SV	29–38	**Effective**	**Effective**	–
F	Spring 2005-1	OP	SV-1	9	**Contrary**	**NS**	**Effective**
		OP	SV-2	21	**Contrary**	**Effective**	–
		OP	SV-3	31	**Contrary**	**Effective**	–
		SV-1	SV-2	12	**Effective**	**Effective**	–
		SV-1	SV-3	22	**Effective**	**Effective**	–
		SV-2	SV-3	10	**NS**	**NS**	–
G	Spring 2005-2	OP	SV	10	**NS**	**Effective**	–
H	Winter 2005	OP	SV	17	**NS**	**Contrary**	–
I	Summer 2001	OP	SV	13–17	**NS**	**Effective**	**NS**

Under discussion

How can we incorporate conceptual frameworks into IBMs?





Is there any special characteristics in growth–survival dynamics of small pelagic fish?

(small pelagic fish vs large pelagic fish, demersal fish, flatfish, coral reef fish, freshwater fish, etc.)