PICES 2012

Environmental windows for small pelagic fish in the western North Pacific: How do their vital parameters respond to climate variability and change?

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PICES 2012 Annual Meeting
Hiroshima, Japan, October 12–21, 2012
Invited talk, Session 3 (S3-8802), October 18 (Thursday)

Role of this talk

S3 **POC Topic Session**
Challenges in understanding Northern Hemisphere ocean climate variability and change

Co-Sponsored by CLIVAR and ICES

Co-Convenors: *Jürgen Alheit (ICES/Germany), Emanuele Di Lorenzo (PICES/USA), Michael Foreman (PICES/Canada), Shoshiro Minobe (PICES/Japan), Hiroaki Saito (PICES/Japan) and Toshio Suga (CLIVAR/Japan)*

Physical climate variability and change exert substantial impacts on marine ecosystems, particularly on longer timescales because of the longer ocean memory compared with the atmosphere, and the cumulative effects on marine ecosystems. On a centennial scale, climate changes due to anthropogenic forcings may dominate over natural variability, but variations on decadal or shorter timescales may be mainly due to natural climate variability. Furthermore, natural climate variability can be modified via climate changes. Therefore, a correct understanding of the mechanisms underlying climate variability and change should be the basis for understanding and predicting future conditions of the North Pacific and North Atlantic. For the North Pacific there is no widely accepted consensus on the mechanisms governing decadal-to-multidecadal climate variability, and this mainly reflects the uncertainty of how, or even whether, the mid-latitude ocean influences the atmosphere. Some linkages between processes, such as oceanic memory due to Rossby wave propagation, are generally accepted, and predictability associated with these processes may also be important for understanding marine ecosystem impacts. It is also unclear if teleconnection dynamics between the North Pacific, North Atlantic and the Arctic exert an important control on the ocean's decadal climate state. This session brings together researchers of marine ecosystems, physical oceanography and climate to share ideas about what physical parameters and processes are important in understanding and predicting the response of specific marine ecosystems to climate forcing. Through collaboration among PICES, CLIVAR and ICES, this session invites contributions exploring important developments in the research field of the North Pacific climate variability and change, including physical environmental variations and their predictability, teleconnection dynamics between oceanic basins, such as the Pacific and Atlantic Oceans, and linkages between physical conditions and marine ecosystems.

"This session brings together researchers of marine ecosystems, physical oceanography and climate to share ideas about what physical parameters and processes are important in understanding and predicting the response of specific marine ecosystems to climate forcing."

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Objective is to show …

1. How dramatically environmental variability could regulate survival probability of small pelagic fish

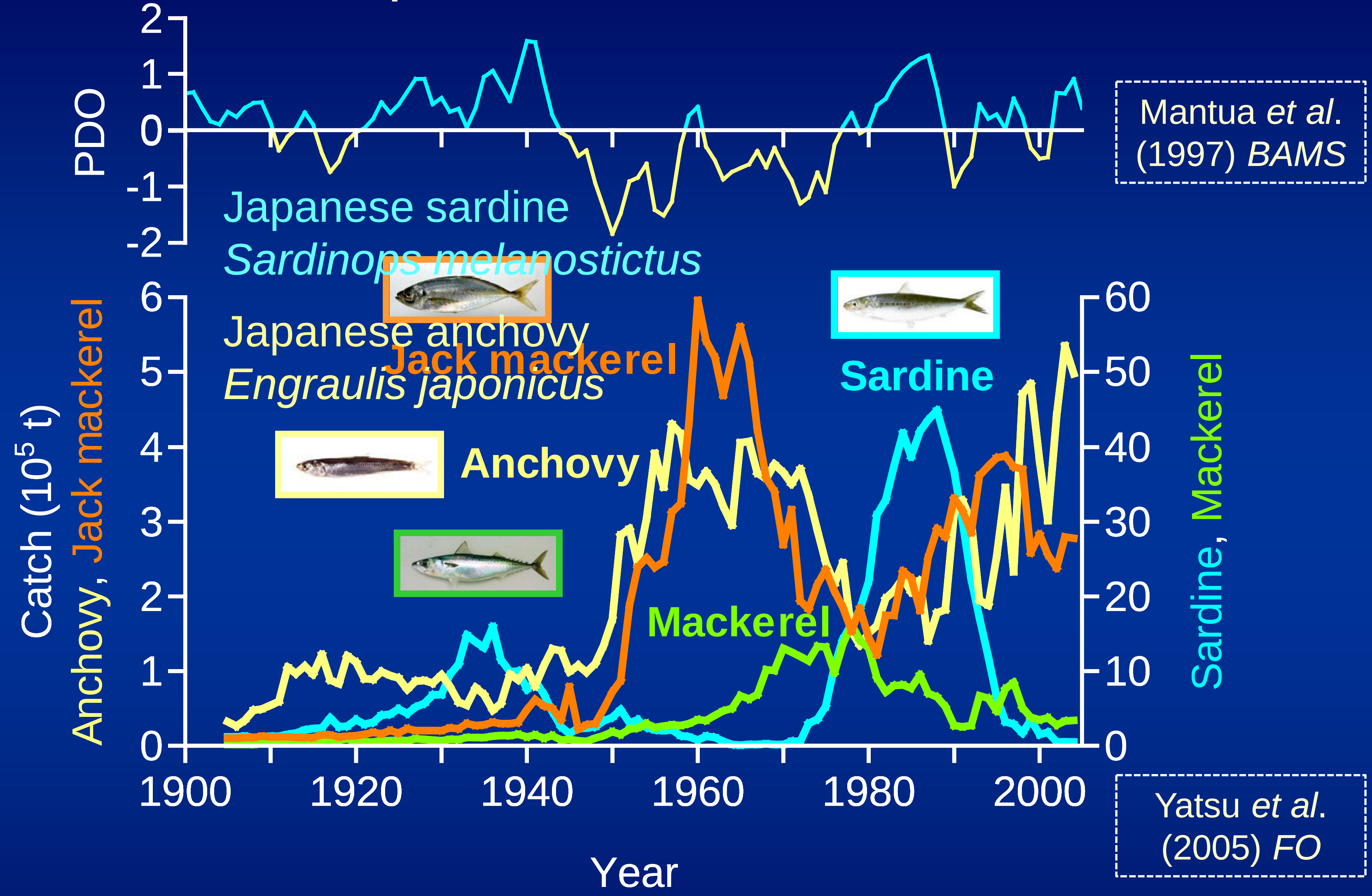
- Introducing the "growth–survival" paradigm

2. How differently the similar environmental condition could affect the population dynamics of different species.

- Reviewing several hypotheses
- Comparing responses of vital parameters to environmental factors among multi-species

Small pelagic fish in the Kuroshio Current system

Species alternations



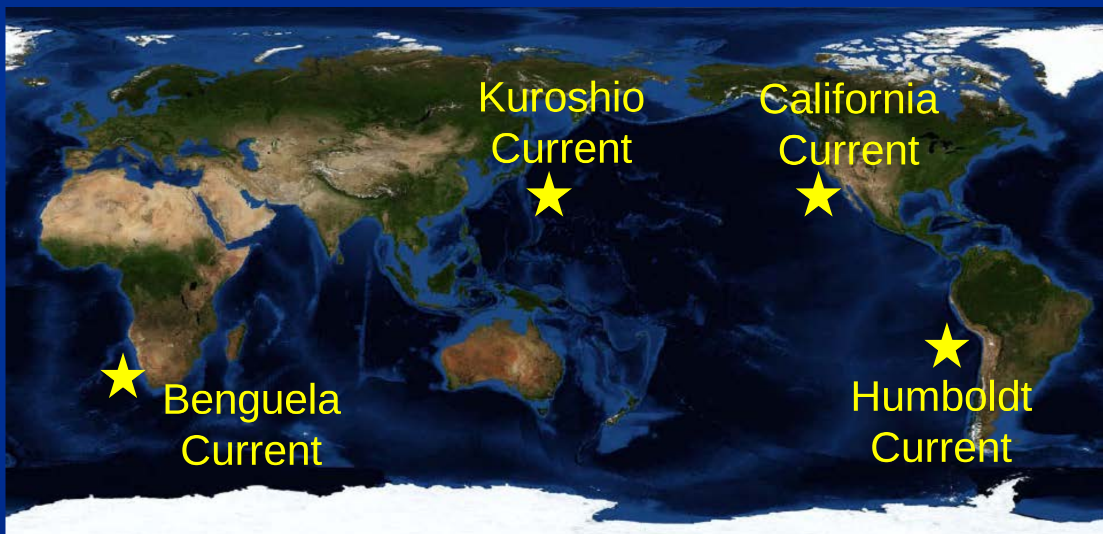
Long-term landing histories of small pelagic fish in waters around Japan in response to Pacific Decadal Oscillation (PDO).

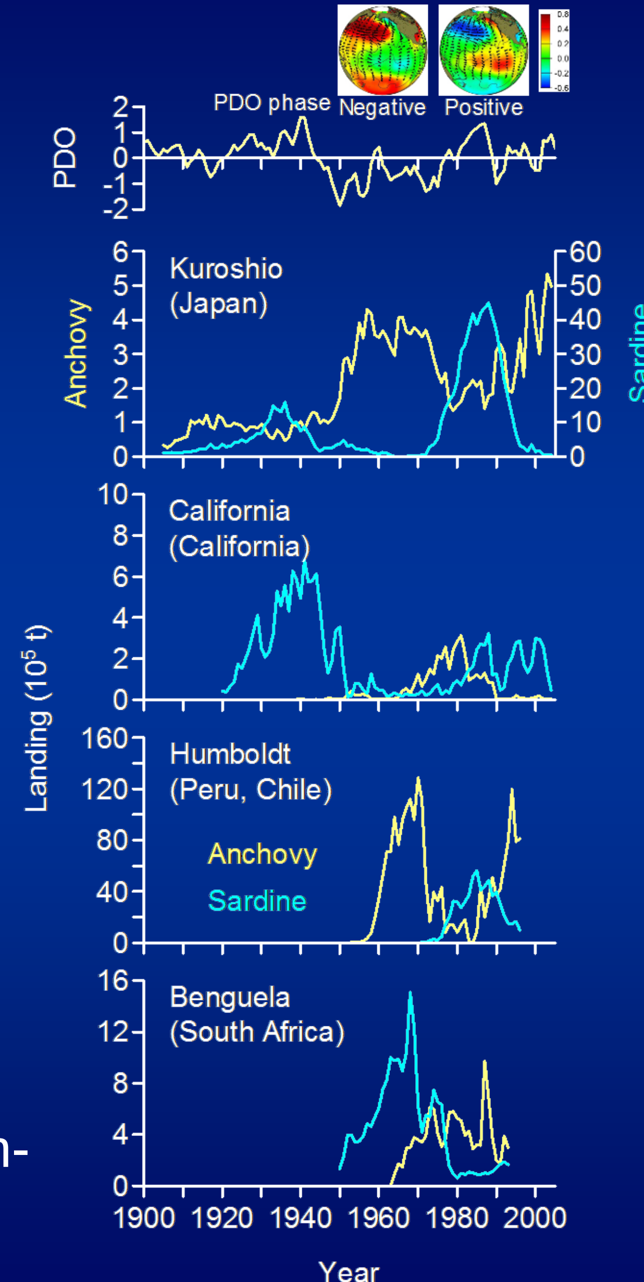
Takasuka *et al*.

Species alternations

Four different current systems

Anchovy *Engraulis* spp.
Sardine *Sardinops* spp.





- The patterns of species alternations tended to be synchronous among the Pan-Pacific regions and asynchronous between the Pan-Pacific regions and the Benguela region.

Key questions

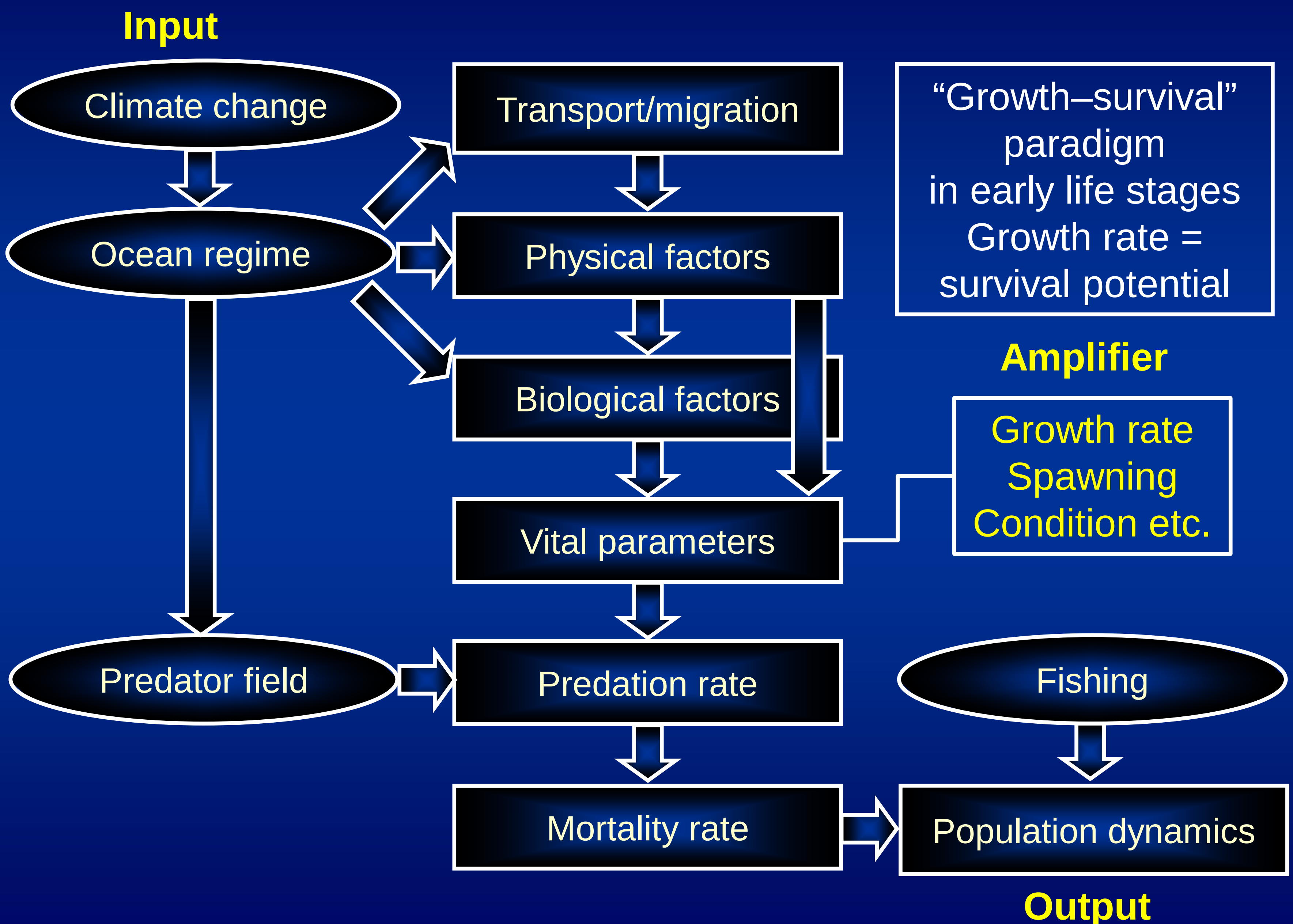
Why do even subtle environmental changes sometimes trigger dramatic alternations?

Why do anchovy flourish and sardine collapse or *vice versa* under the same ocean regime?

Concept:

Differential responses of vital parameters to environmental factors constitute a key to understand biological processes linking climate variability to species alternations

Cascade


Input
Climate change
Ocean regime
Predator field
Transport/migration
Physical factors
Biological factors
Vital parameters
Predation rate
Mortality rate
"Growth–survival" paradigm in early life stages Growth rate = survival potential
Amplifier
Growth rate
Spawning
Condition etc.
Fishing
Population dynamics
Output

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Paradigm/mechanisms

"Growth–survival" paradigm in early life stages

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

Functional mechanisms

Why do they survive better?

I. "Bigger is better" (Miller *et al*. 1988)

Growth rate determines somatic size influencing survival advantages.

II. "Stage duration" (Chambers & Leggett 1987, Houde 1987)

Growth rate determines high mortality larval stage duration.

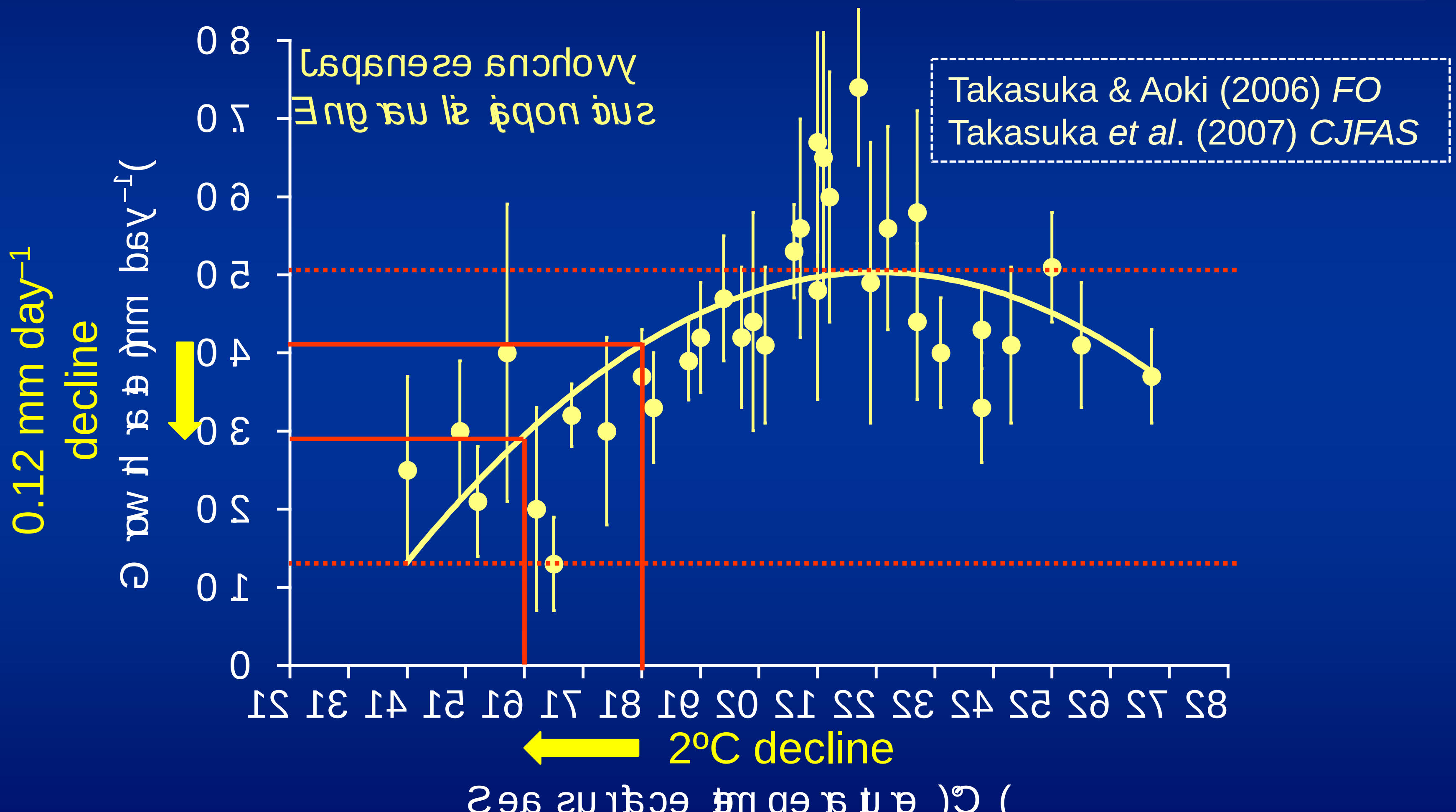
III. "Growth-selective predation" (Takasuka *et al*. 2003, 2004, 2007)

Growth rate *per se* exerts direct impacts on predation mortality.

What's the consequence of environmental variability?

Consequence of 2ºC change

Temperature decline: 2ºC → Growth decline: 0.12 mm day^{-1} → Growth decline: 31% of the range



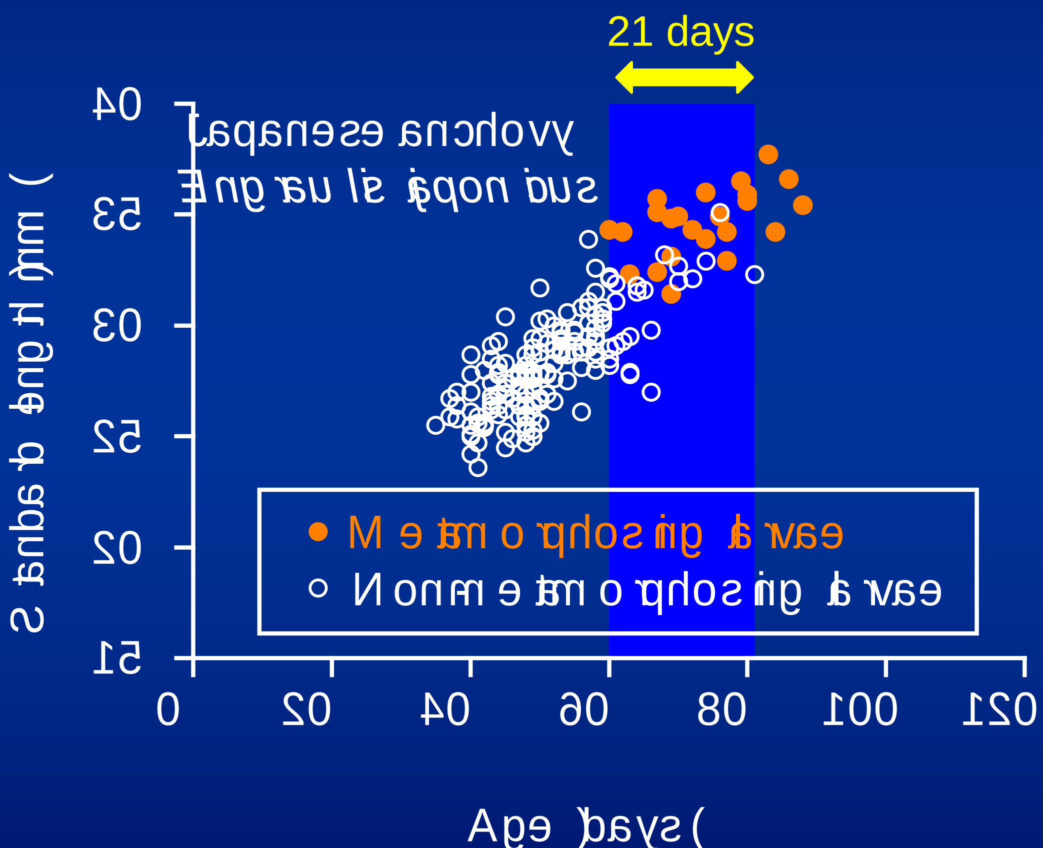
Relationship of growth rate to temperature for Japanese anchovy larvae.

Stage duration mechanism

Growth decline:
31% of the range

→

Metamorphosis:
6.5 days delay



Assuming
mortality rate
= 30% day^{-1}
survival rate
= 70% day^{-1}

$(0.70)^{6.5} = 0.098$

Cumulative
survival probability
during larval stage:
multiplied by 9.8%

9.8% against 100%

Consequence
of 2ºC change:
ca.10 times difference
in survival probability

Size-at-age of the metamorphosing larvae vs non-metamorphosing larvae of Japanese anchovy.

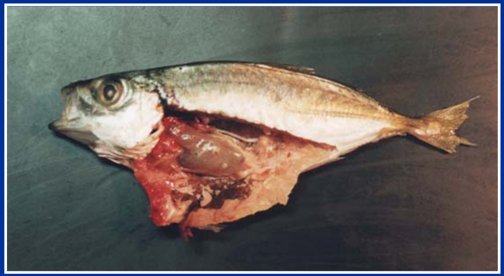
Takasuka *et al*. (2004) *MEPS*

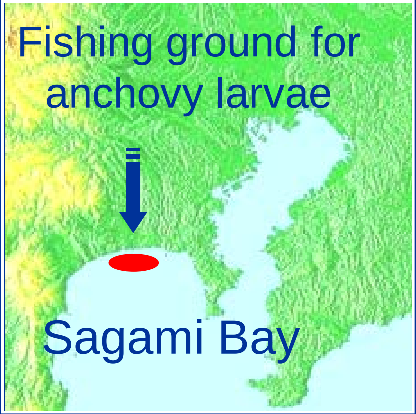
Growth-selective predation

Field sampling

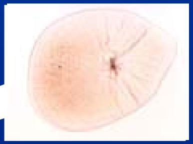
Takasuka *et al*. (2003, 2004a,b, 2007) *MEPS*

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



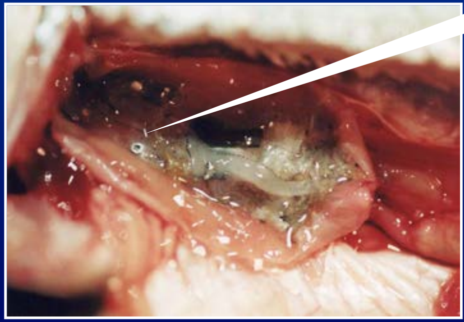


Growth comparison



Otolith microstructure analysis

Ingested larvae



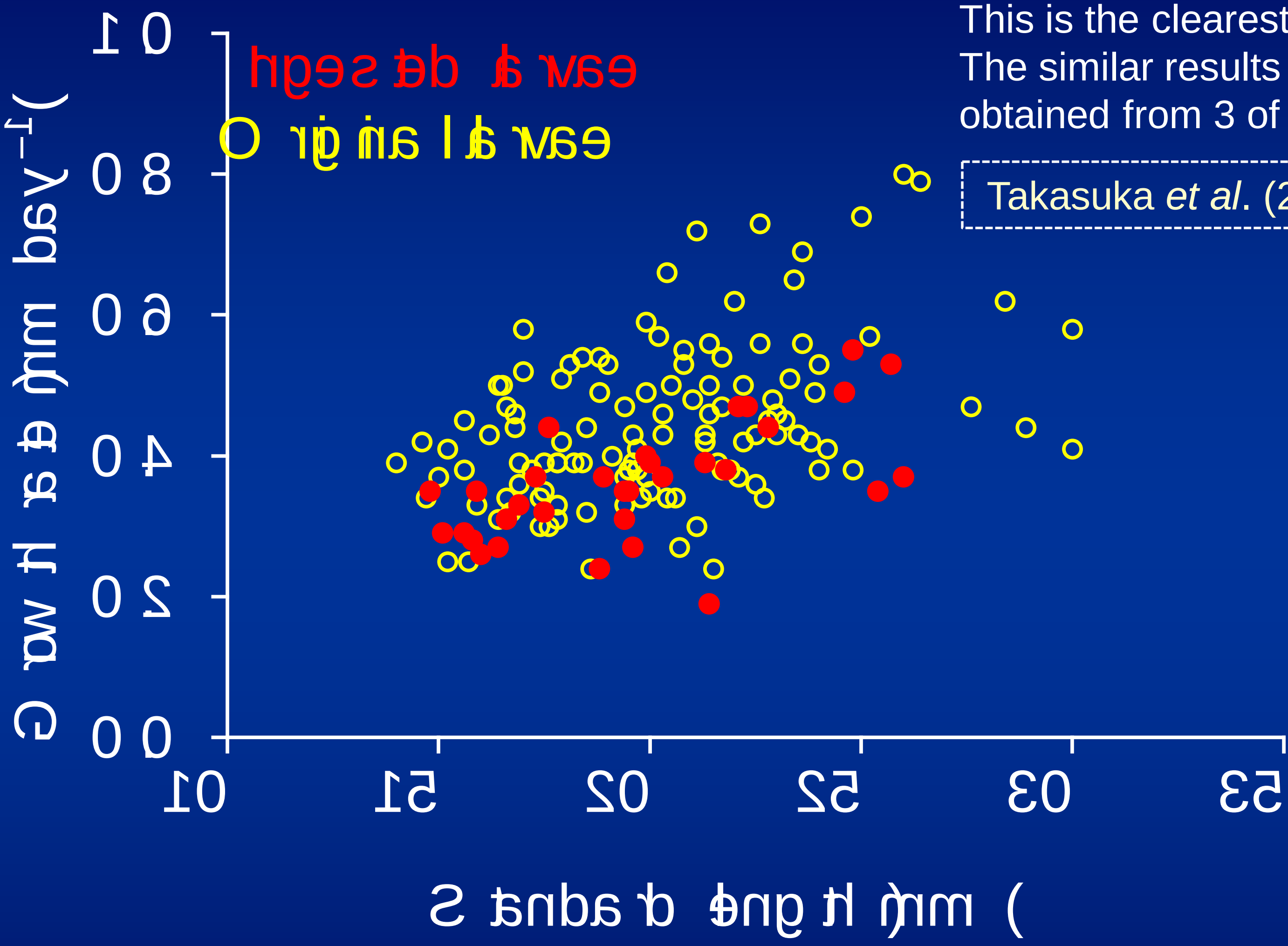
The larvae actually ingested by the predators

Original larvae

The surviving larvae from the original populations

Takasuka *et al*.

Growth-selective predation



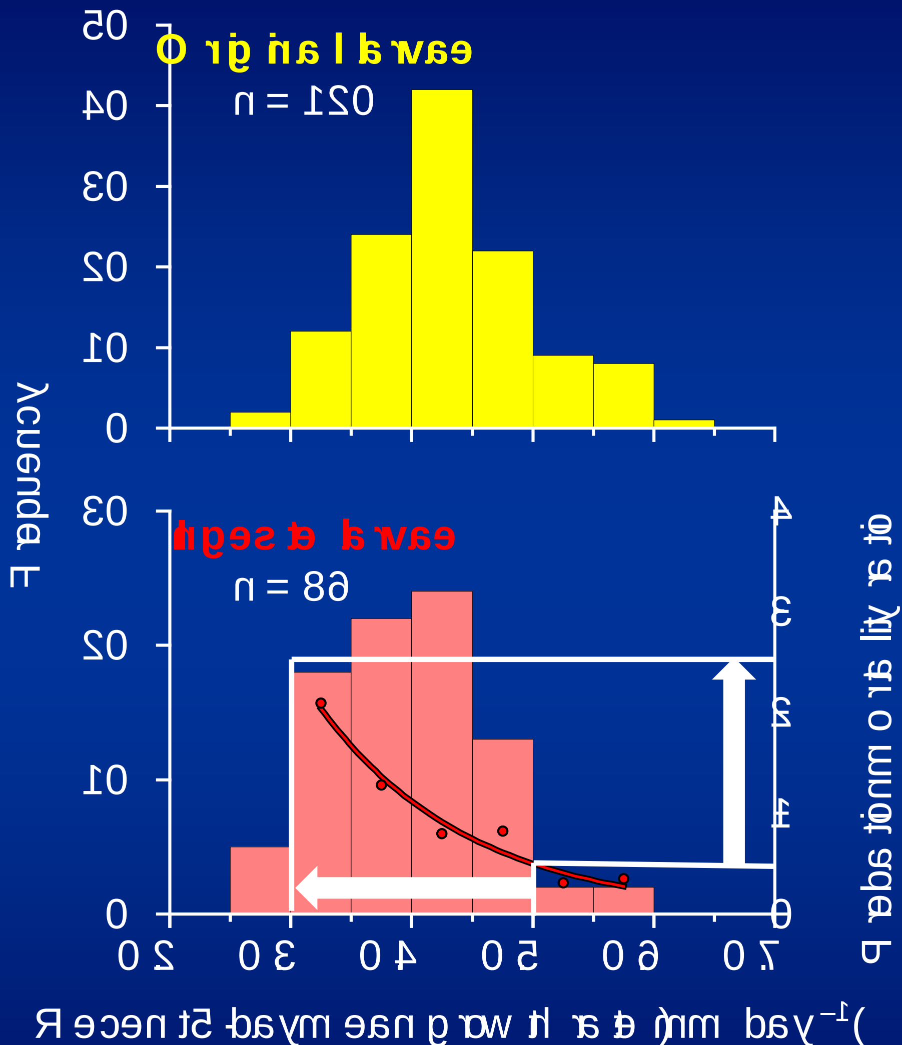
This is the clearest example.
The similar results were
obtained from 3 of 5 samples.

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

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

Relative predation mortality

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



Predators:
Pacific round herring
Japanese jack mackerel

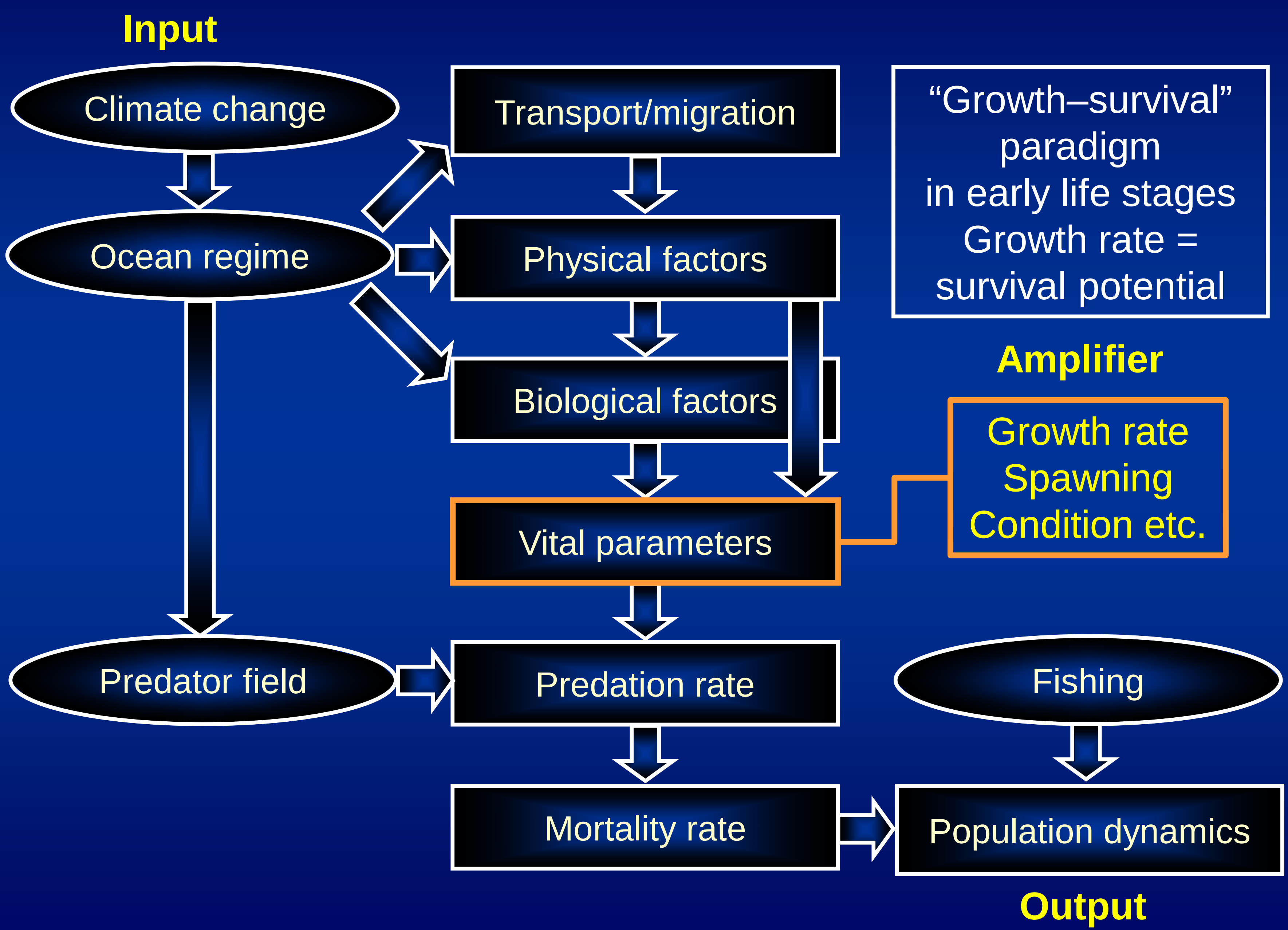
Growth decline:
0.20 mm day^{-1}
(0.50 to 0.30 mm day^{-1})

Predation mortality ratio increased from 0.5 to 2.5

Instantaneous 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.

Cascade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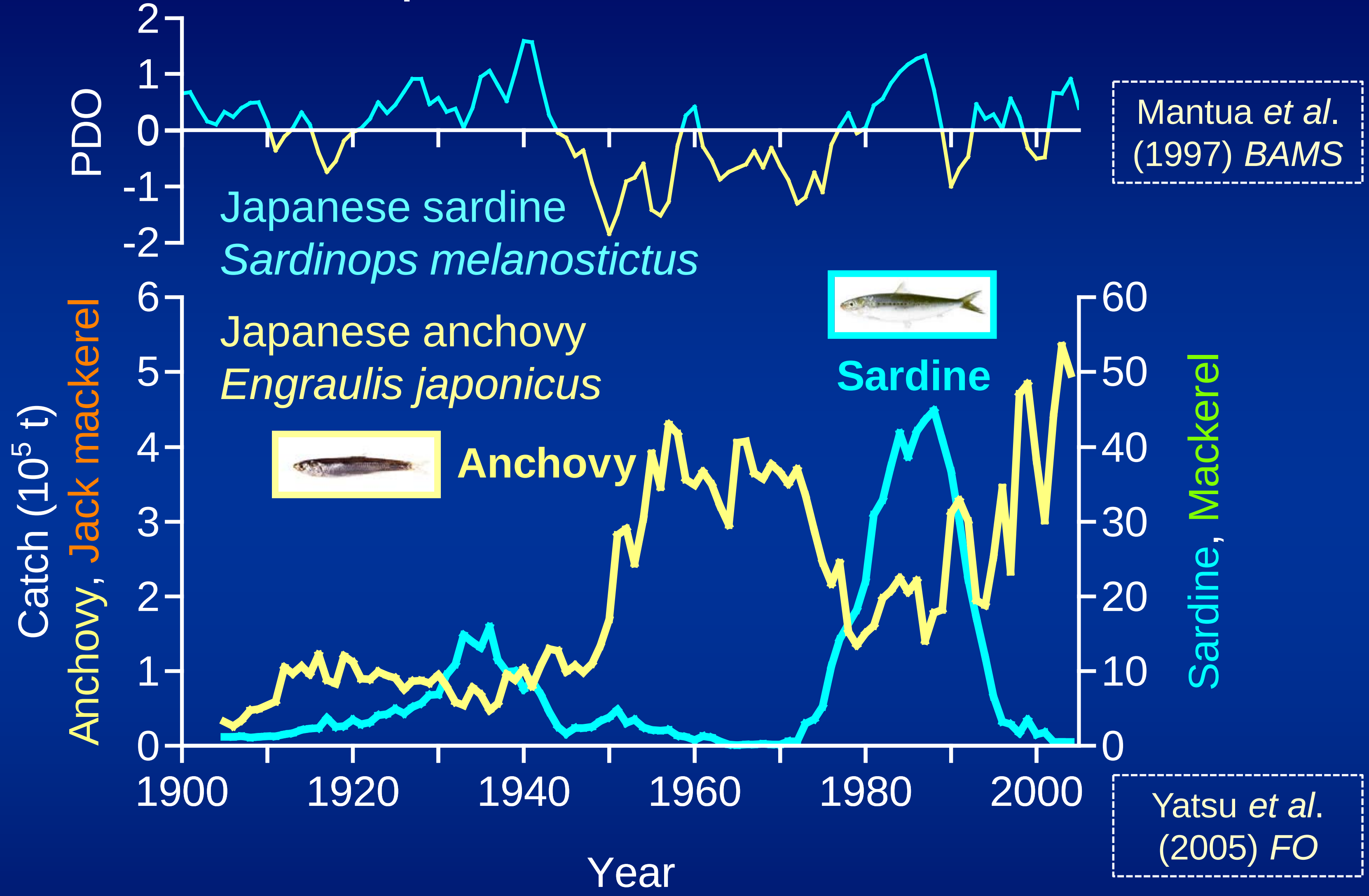
Small pelagic fish in the Kuroshio Current system

Takasuka *et al*.

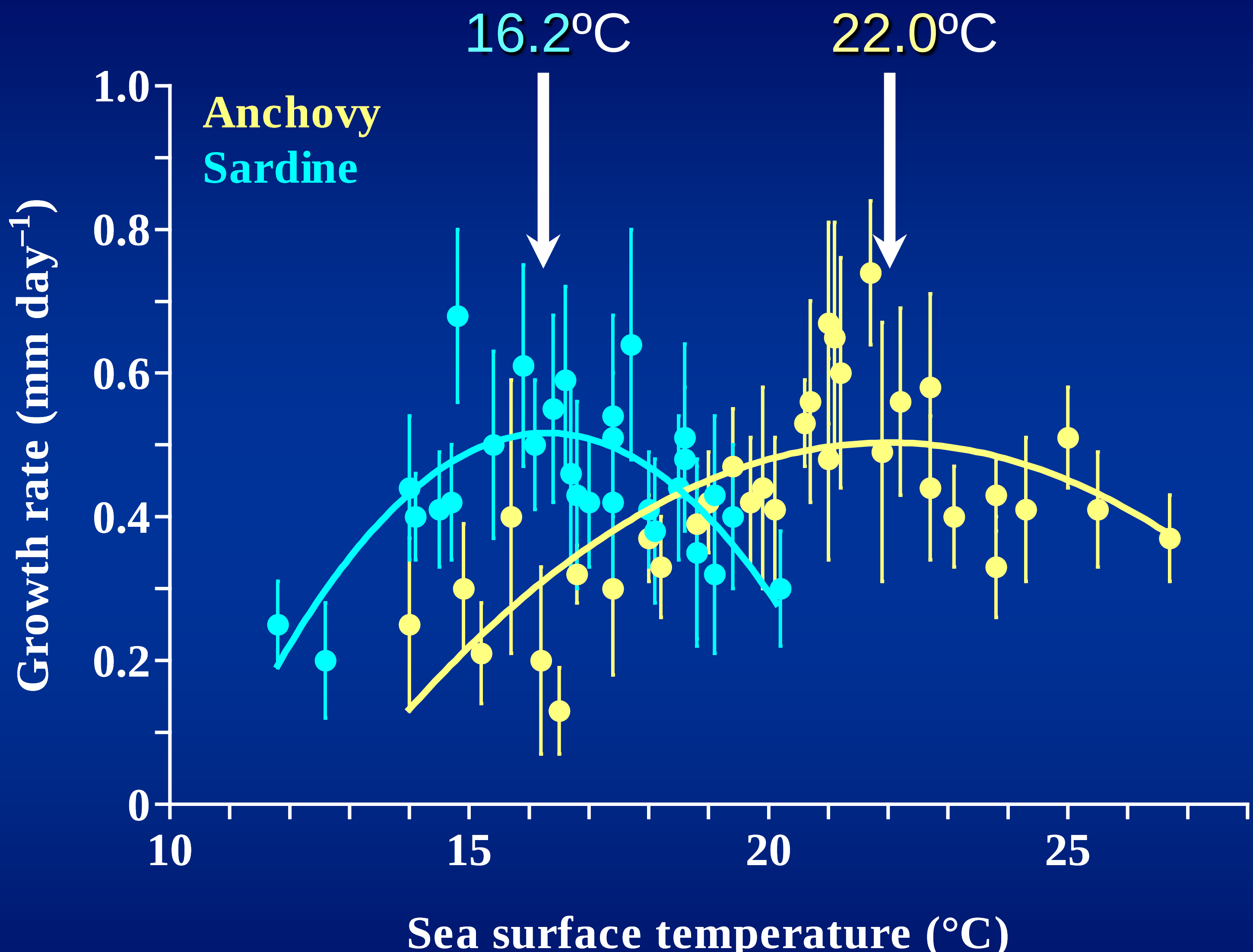
Species alternation



Long-term landing histories of small pelagic fish in waters around Japan in response to Pacific Decadal Oscillation (PDO).

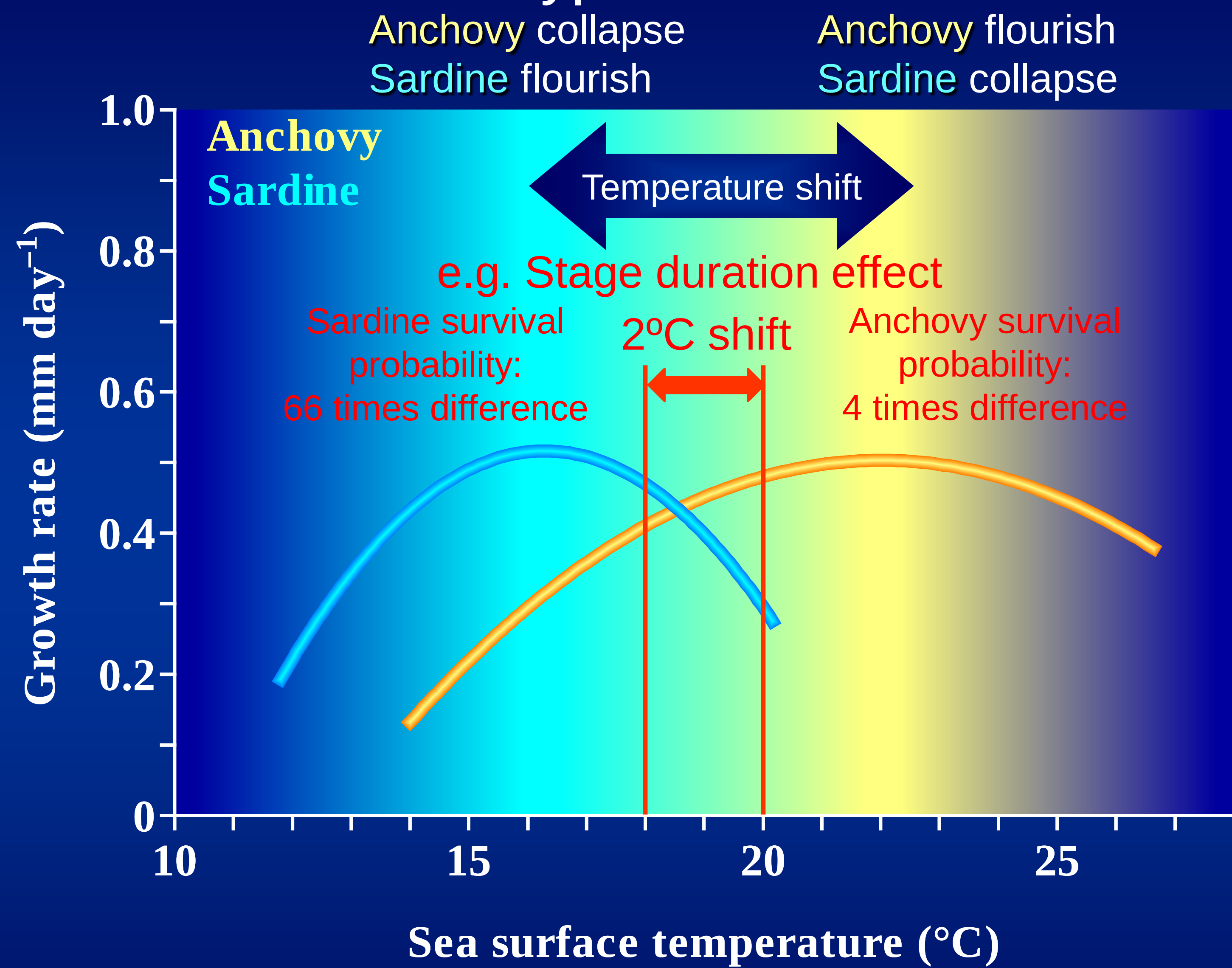
Takasuka *et al*.

Optimal growth temperatures



Relationship between recent 3-day mean growth rates and sea surface temperature for anchovy and sardine larvae (Takasuka *et al*. 2007 *CJFAS*).

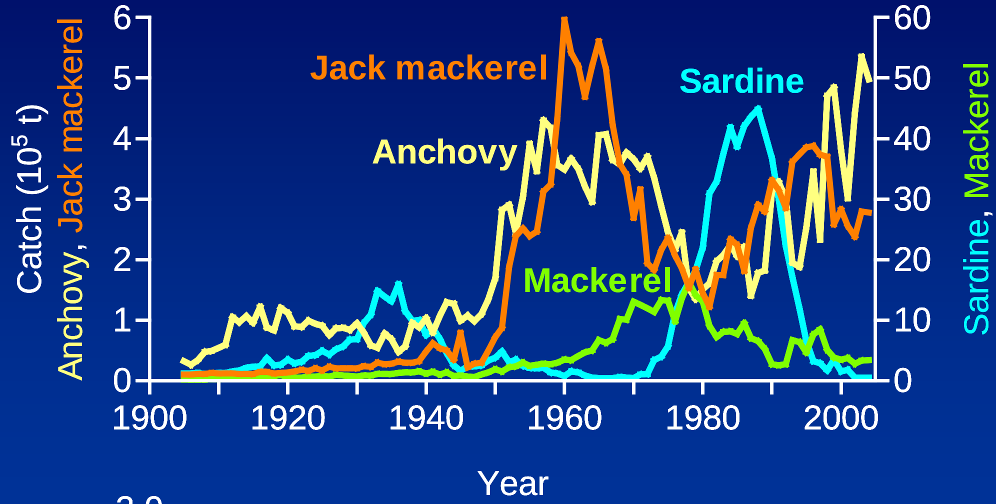
Hypothesis

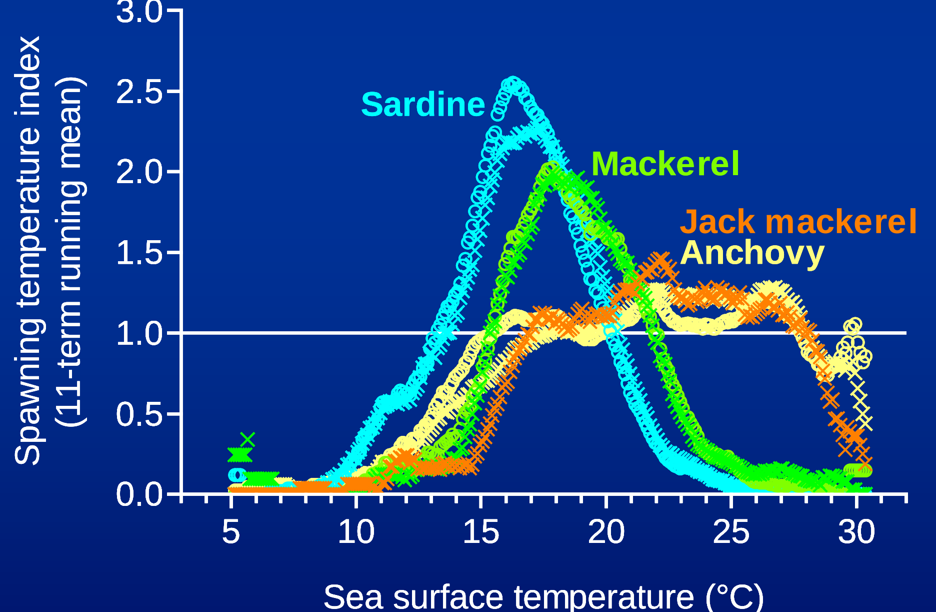


Conceptual framework of the “optimal growth temperature” hypothesis (Takasuka *et al*. 2007 *CJFAS*).

Takasuka *et al*.

Spawning temperatures





Anchovy

Sardine

Mackerel

Jack mackerel

Similarities and differences in spawning temperature patterns represent those in the long-term population dynamics (Takasuka *et al*. 2008 *MEPS*).

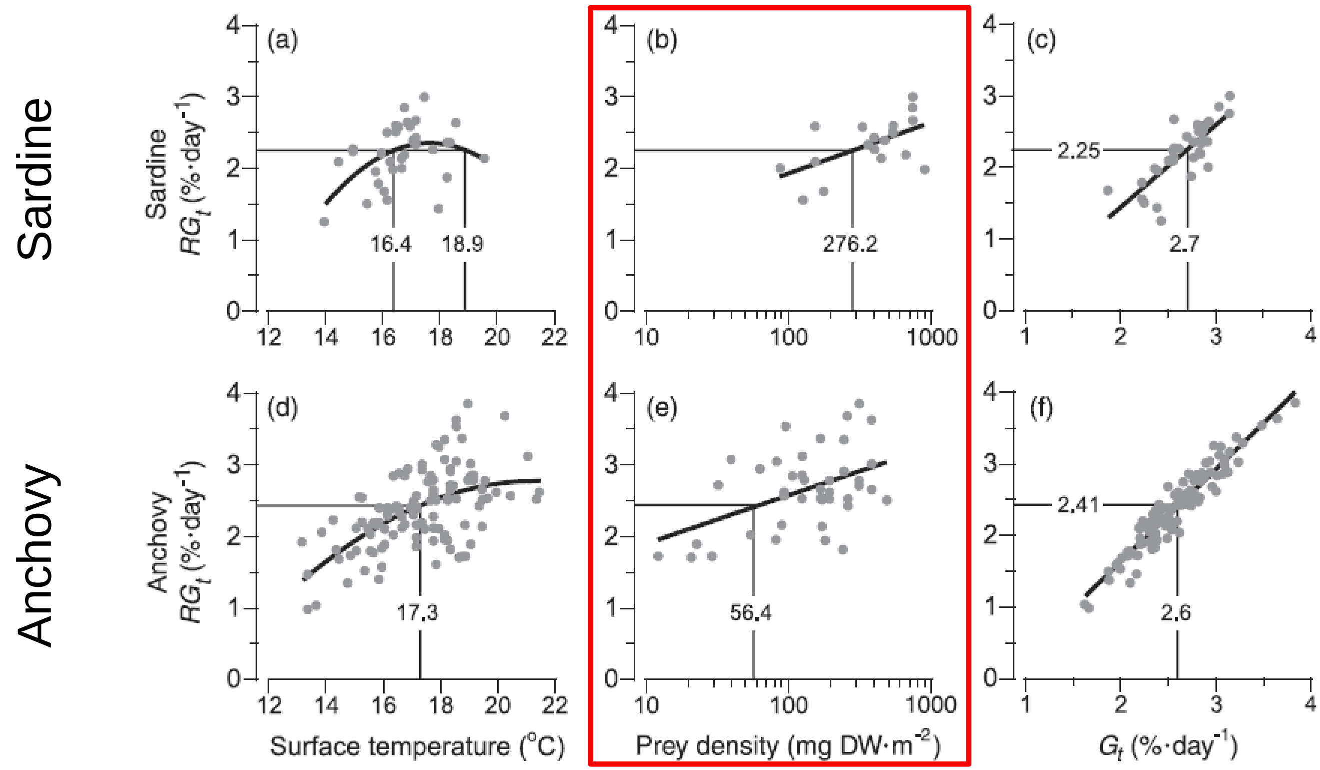
Takasuka *et al*.

Temperature & Food

Contrasting responses in larval and juvenile growth to a climate–ocean regime shift between anchovy and sardine

2009 in *CJFAS*

Motomitsu Takahashi, Yoshiro Watanabe, Akihiko Yatsu, and Hiroshi Nishida



Relationships of growth rates to temperature and prey density for anchovy and sardine larvae and early juveniles in the Kuroshio–Oyashio transition region (Takahashi *et al*. 2009 *CJFAS*).

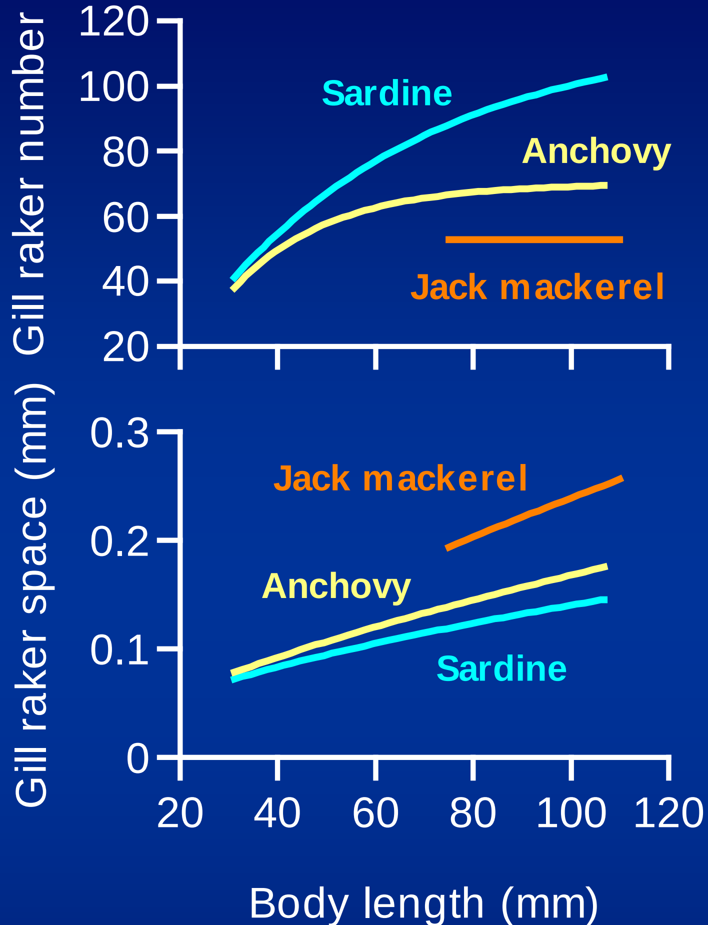
Trophic dissimilarity

Cool regime	Physical forcing (wind, etc.)	Warm regime
Intermittent mixing (upwelling, cool)	Water column (temperature)	Highly stable (warm)
Larger-cell (diatom) High biomass	Phytoplankton community	Smaller cell (flagellate) Low biomass
Larger copepods	Zooplankton community	Smaller copepods
Particulate-feeder favored	Pelagic fish community	Filter-feeder favored

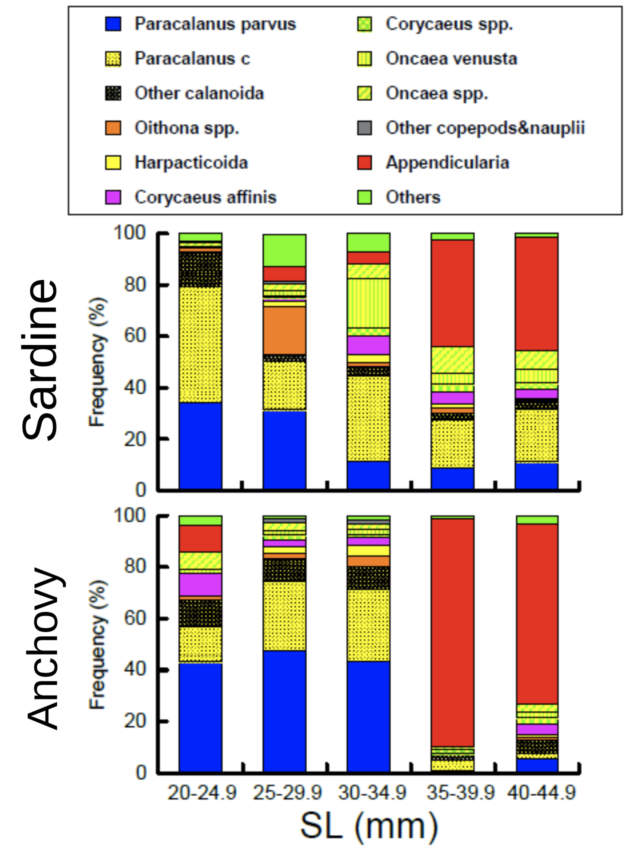
Anchovy ← Differential feeding strategies → Sardine

Conceptual framework of the "trophic dissimilarity" hypothesis from the Benguela Current system (van der Lingen *et al*. 2006 *AJMS*).

Feeding habits



Tanaka *et al*. (2006) *JFB*
van der Lingen *et al*. (2009) *SPACC book*



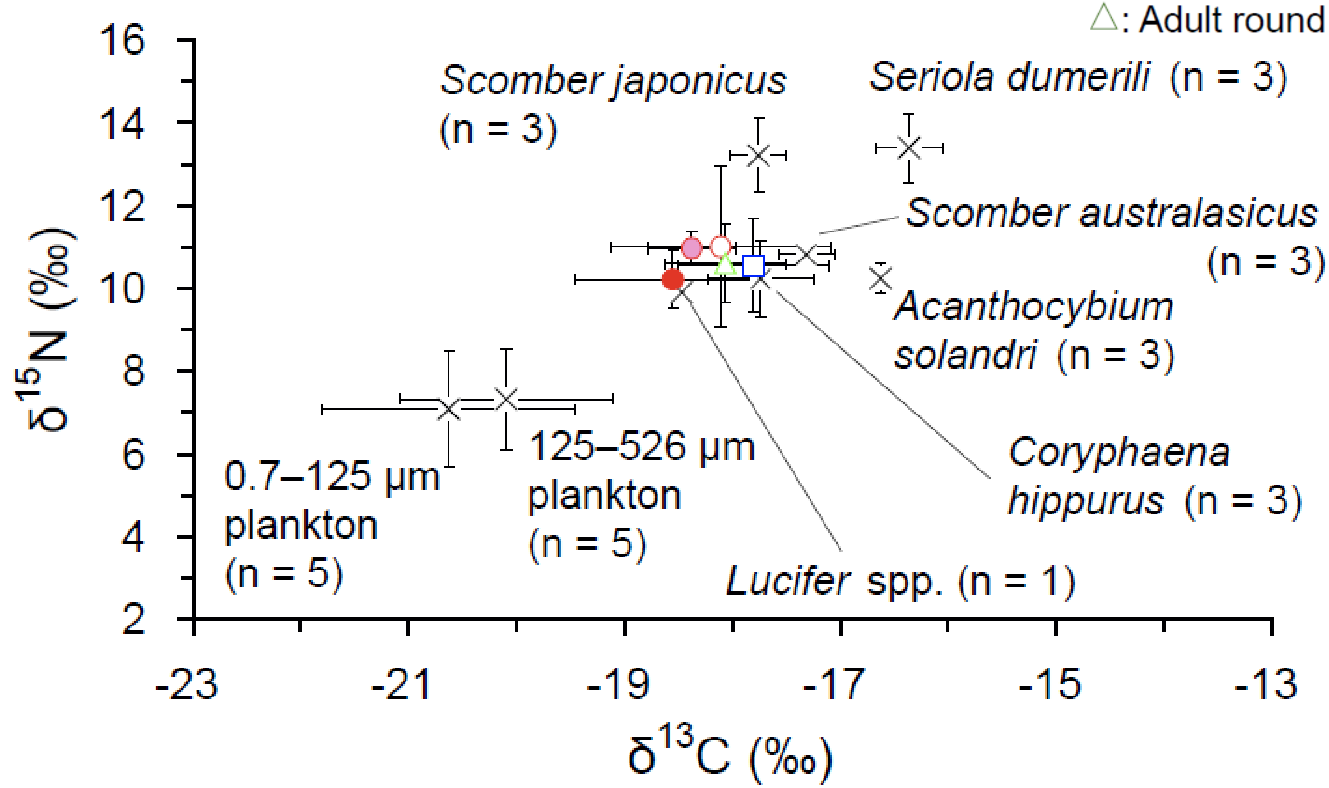
Feeding habits of larvae and juveniles in Tosa Bay.
Okazaki, Y., Kubota, H. *et al*.

Gill raker morphology also differed between anchovy and sardine in the Kuroshio Current system. However, there were not great differences in feeding habit during the early life stages.

Takasuka *et al*.

Trophic similarity?

Comparison of feeding habits and trophodynamics in the Kii Channel
Yasue *et al*. (2011) *MB*, Yasue *et al*. (submitted)



- Strong trophic overlaps throughout the life histories among the species.
- We conclude that anchovy and sardine are ecologically congeneric species in terms of trophic position in this region.

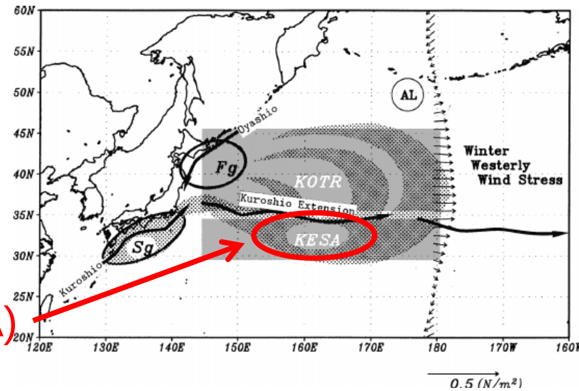
Takasuka *et al*.

Winter SST in KESA

Population decline of the Japanese sardine, *Sardinops melanostictus*, in relation to sea surface temperature in the Kuroshio Extension

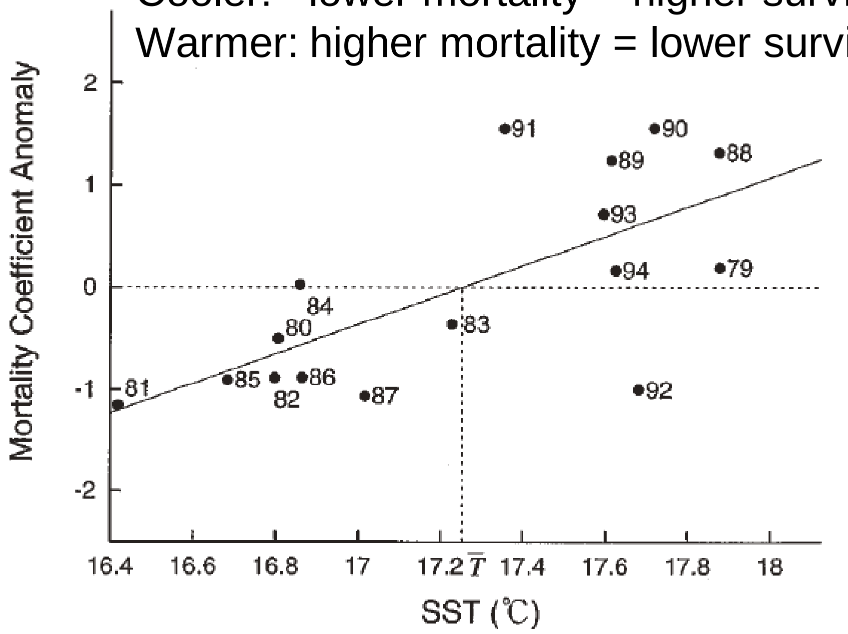
Masayuki Noto and Ichiro Yasuda

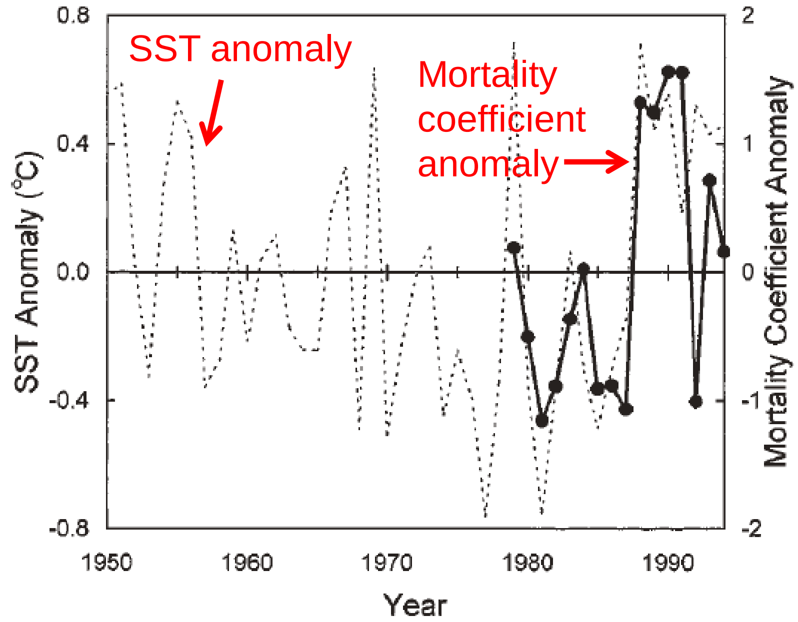
1999 in *CJFAS*



Kuroshio Extension and its southern recirculation area (KESA)

Cooler: lower mortality = higher survival
Warmer: higher mortality = lower survival

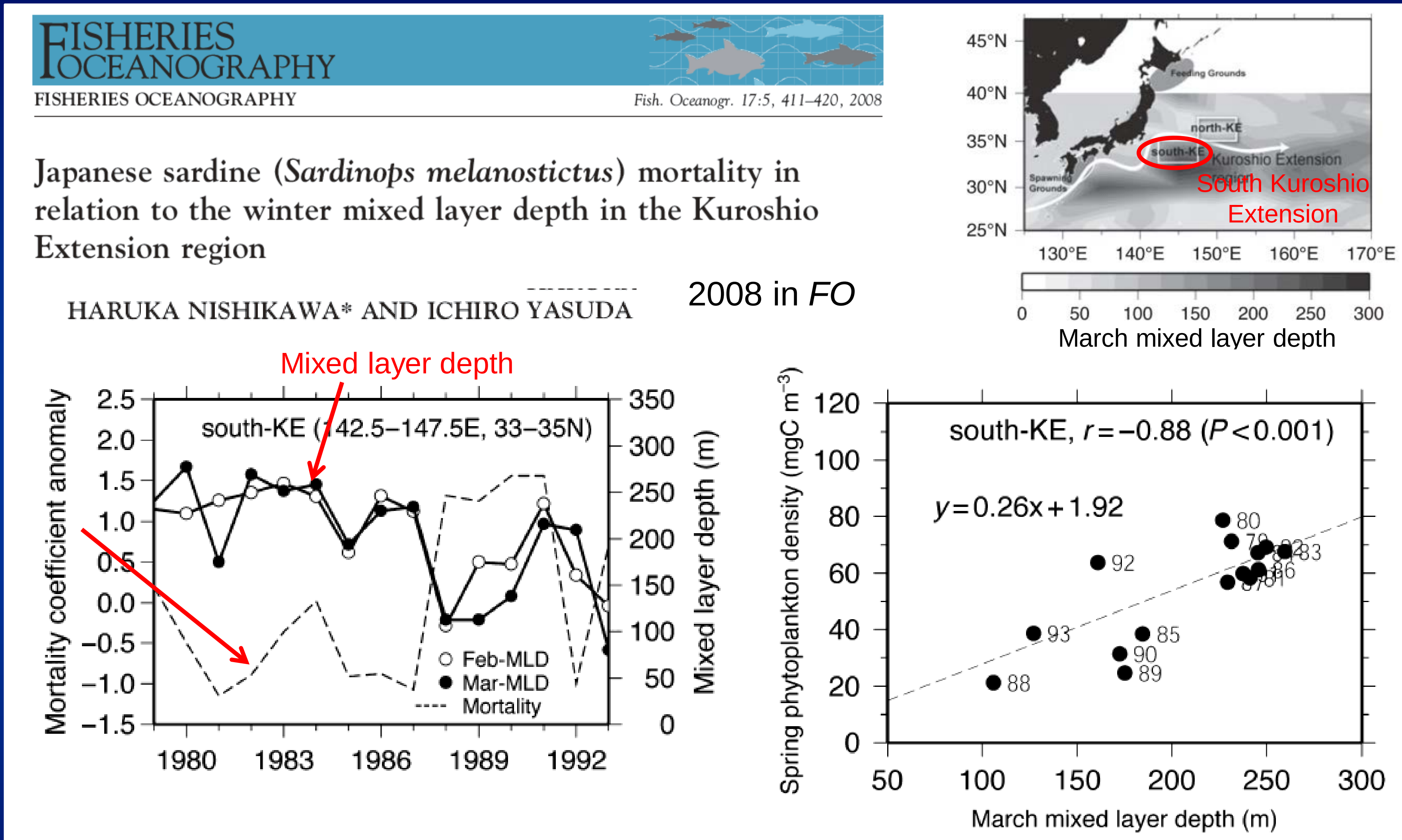




Relationships of natural mortality coefficient anomaly from postlarva to age 1 to February SST (left) and February SST anomaly (right) in KESA for Japanese sardine (Noto & Yasuda 1999 *CJFAS*).

Takasuka *et al*.

Winter mixed layer depth



Natural mortality coefficient anomaly from postlarva to age 1 of Japanese sardine vs February/March mixed layer depth, and spring phytoplankton density vs March mixed layer depth (Nishikawa & Yasuda 2008 *FO*).

Takasuka *et al*.

Winter mixed layer depth

FISHERIES OCEANOGRAPHY

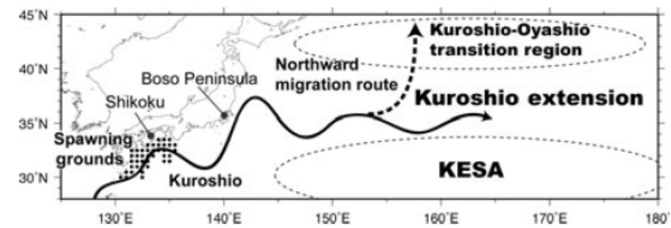
FISHERIES OCEANOGRAPHY *Fish. Oceanogr.* 20:6, 570–582, 2011

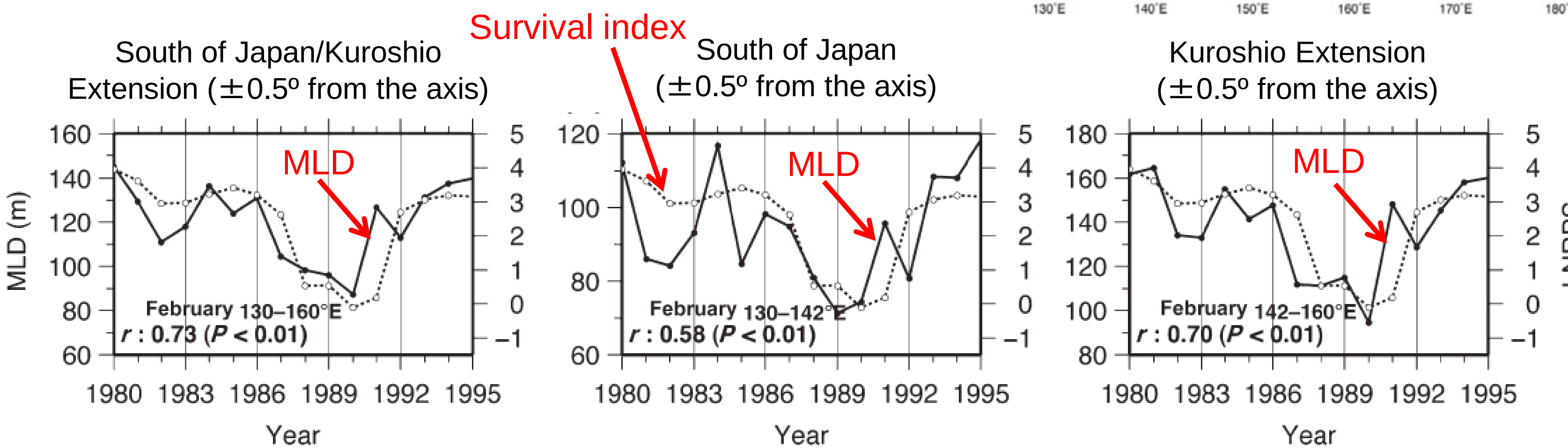
Impact of winter-to-spring environmental variability along the Kuroshio jet on the recruitment of Japanese sardine (*Sardinops melanostictus*)

HARUKA NISHIKAWA,*,† ICHIRO YASUDA AND SACHIHIKO ITOH

2011 in *FO*

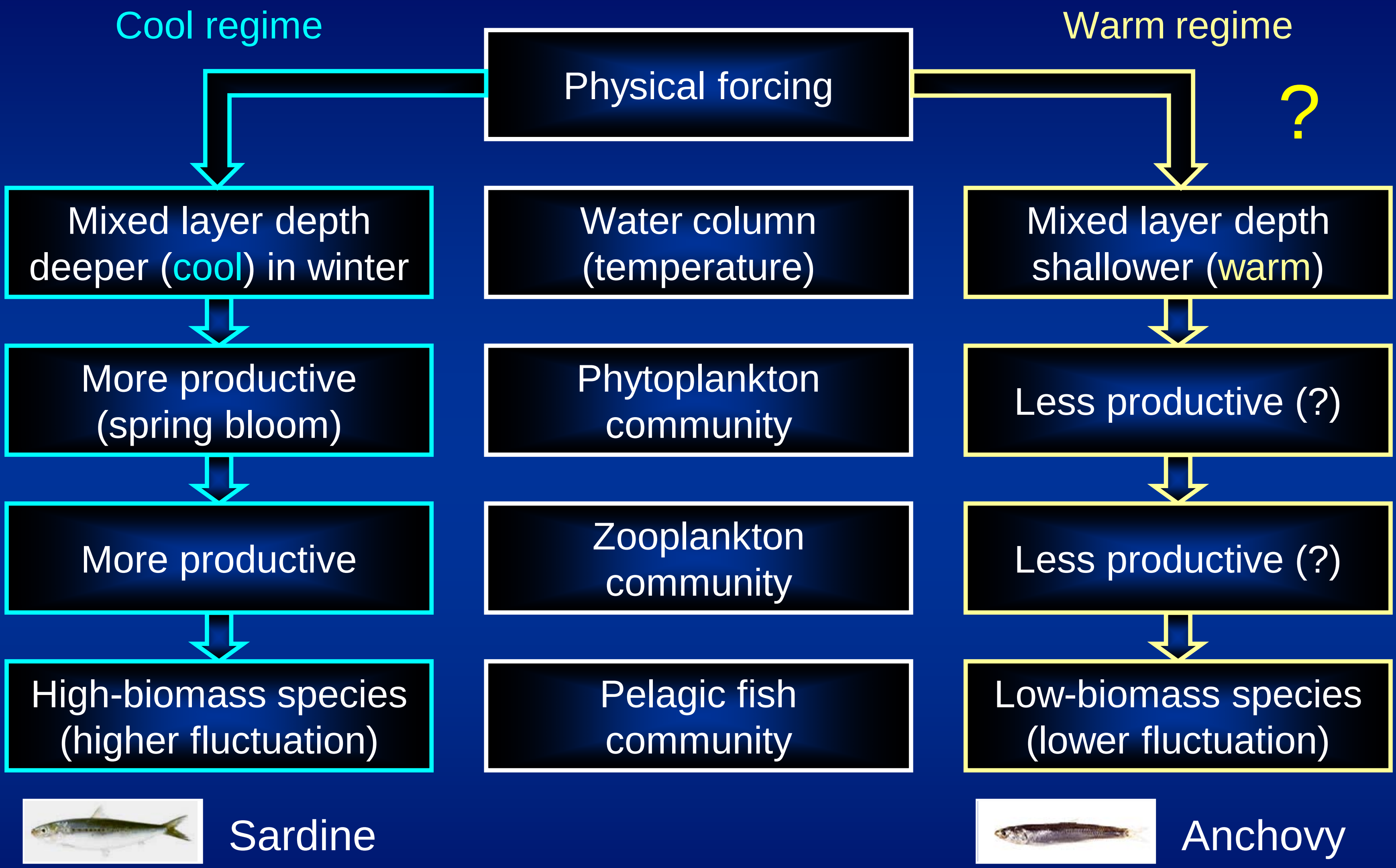
- Ocean general circulation model for the Earth Simulator (OFES)
- “Kuroshio axis coordinates”





Time series data of survival index (ln-transformed recruitment per spawning stock biomass: LNRPS) for Japanese sardine and February mixed layer depth around the Kuroshio axis (Nishikawa *et al*. 2011 *FO*).

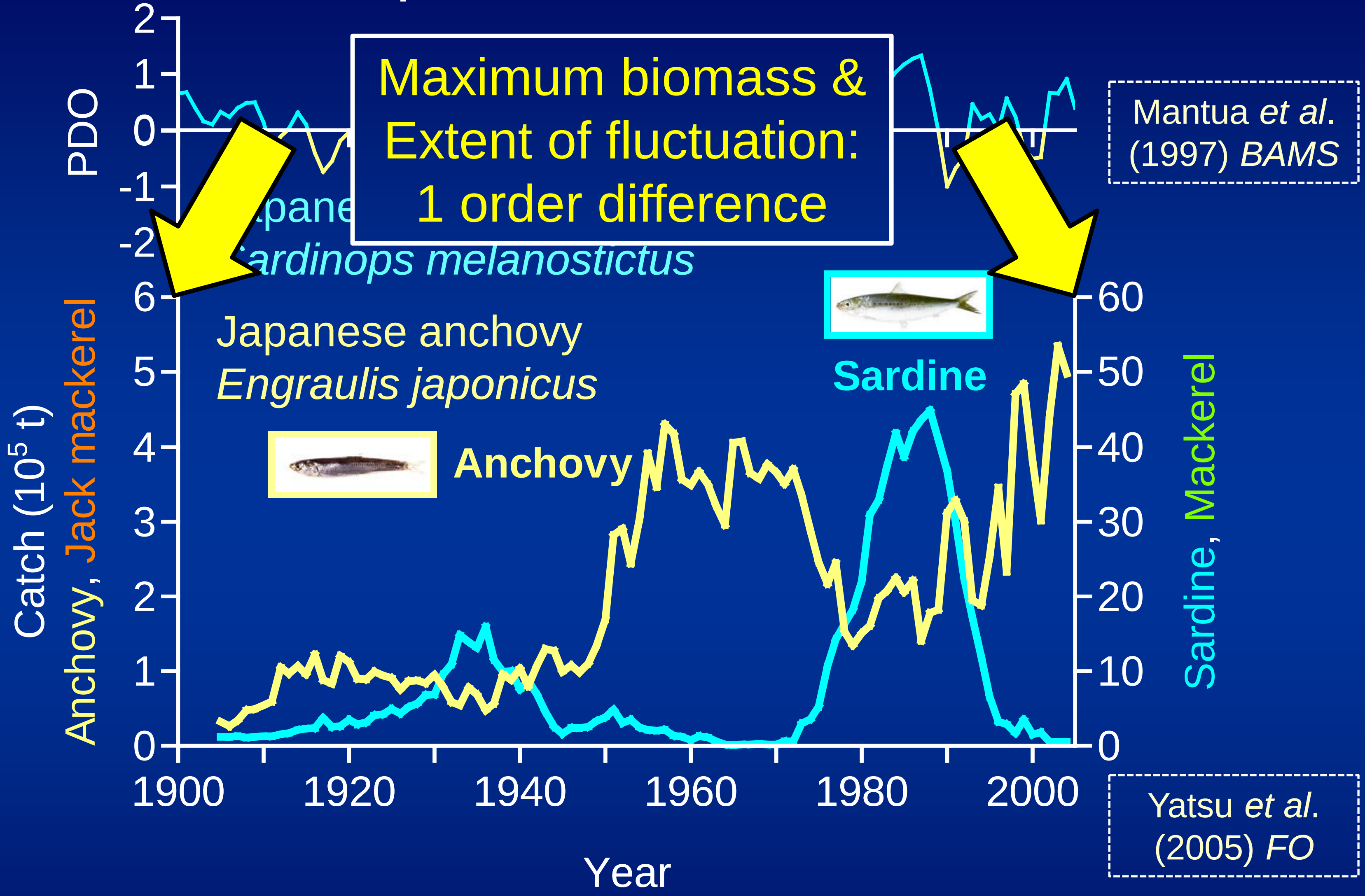
Trophodynamics



Trophodynamics hypothesis in the Kuroshio Current system (keys: winter mixed layer depth & spring plankton bloom in the nursery grounds).

Takasuka *et al*.

Species alternation



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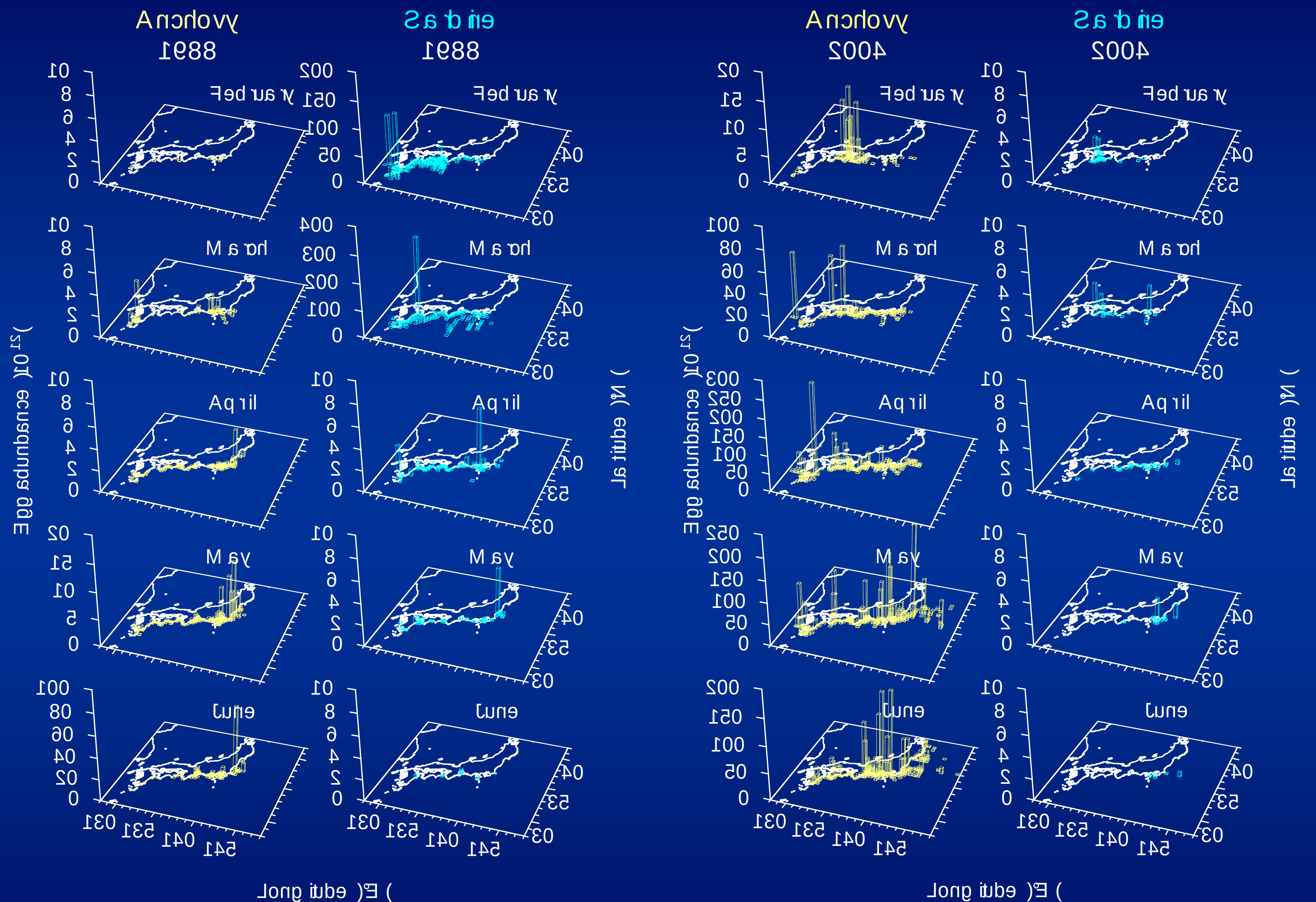
Takasuka *et al*.

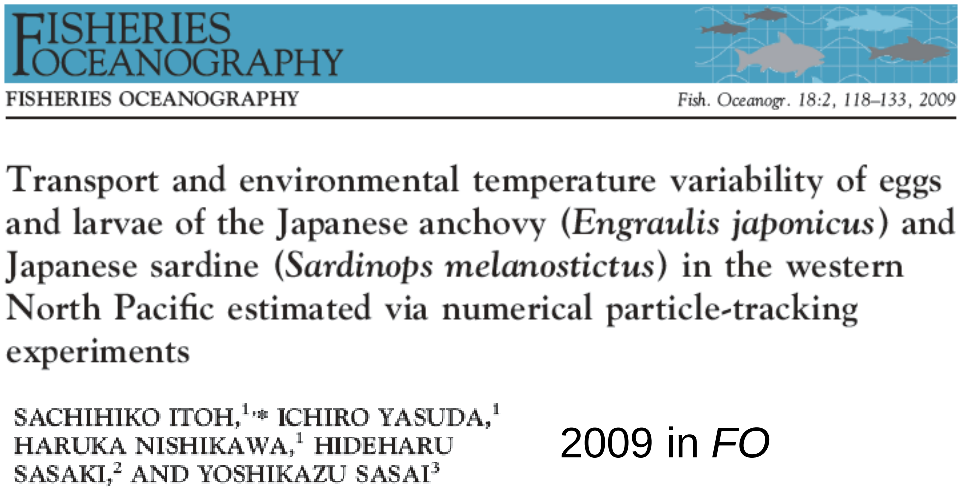
Spawning separation/overlap



Examples of monthly egg abundance distributions of anchovy and sardine in the western North Pacific (Takasuka *et al*. 2008 *MEPS*).

Takasuka *et al*.

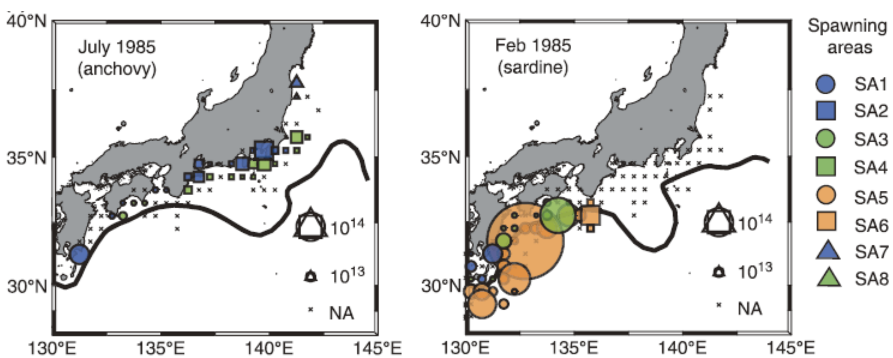
Transport and environments


FISHERIES OCEANOGRAPHY
FISHERIES OCEANOGRAPHY Fish. Oceanogr. 18:2, 118–133, 2009

Transport and environmental temperature variability of eggs and larvae of the Japanese anchovy (*Engraulis japonicus*) and Japanese sardine (*Sardinops melanostictus*) in the western North Pacific estimated via numerical particle-tracking experiments

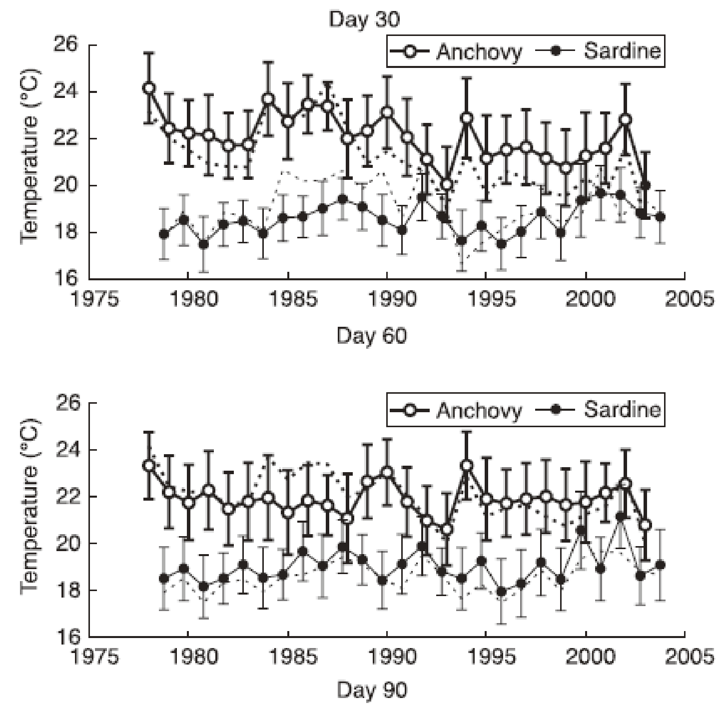
SACHIHIKO ITOH,[1,*] ICHIRO YASUDA,[1] HARUKA NISHIKAWA,[1] HIDEHARU SASAKI,[2] AND YOSHIKAZU SASAI[3]

2009 in *FO*



Considering differences in spawning seasons/grounds

- Ocean general circulation model for the earth simulator (OFES)
- Observed distributions of eggs from 1978 to 2004



Interannual variations of mean temperatures experienced during the transport processes

Numerical particle-tracking experiments to examine the transport and variability in environmental temperature experienced by eggs and larvae of anchovy and sardine (Itoh *et al*. 2009 *FO*).

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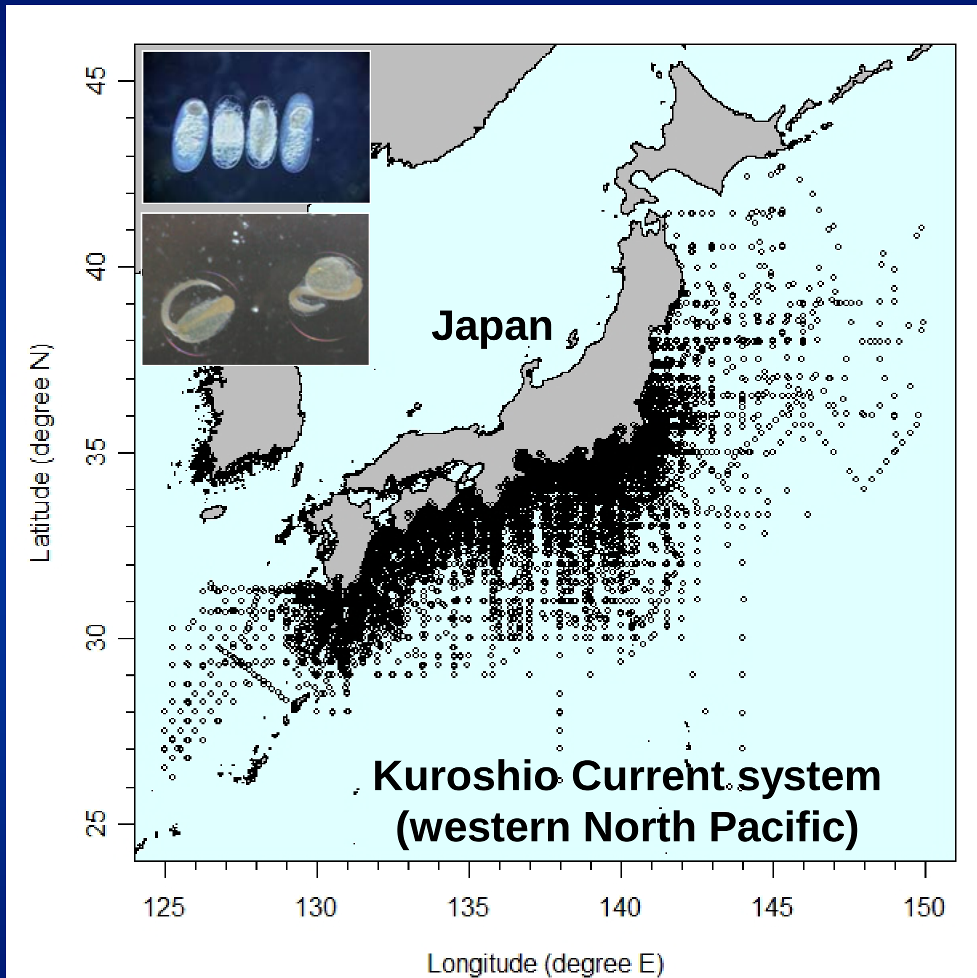
Small pelagic fish in the Kuroshio Current system

Egg survey data set

A long-term data set of monthly egg surveys



- Off the Pacific coast of Japan
- Last 30 years (1978–2007)
- Vertical tows of NORPAC net
- 114,130 samples

Sampling stations in the monthly egg surveys off the Pacific coast of Japan from 1978 to 2007 (Oozeki *et al*. 2007 *CalCOFI*, Takasuka *et al*. 2008 *MEPS*).

GAMs

Spawning responses to multiple environmental factors

Generalized additive models (GAMs) were fitted to egg presence/absence (1/0) data with multiple variables.

Physical factors

- Sea surface temperature (ºC): *SST*
- Sea surface salinity: *SSS*

Biological factors

- Zooplankton volume (ml m^{-2} or μg m^{-3}): *PL*
- Chlorophyll-*a* concentration (mg m^{-3}): *CH*

GAMs with multiple explanatory variables:

$$y = \alpha + s(SST) + s(SSS) + s(\ln(PL)) \text{ or } s(\ln(CH))$$

y: the estimated probability of egg occurrence from 0 to 1

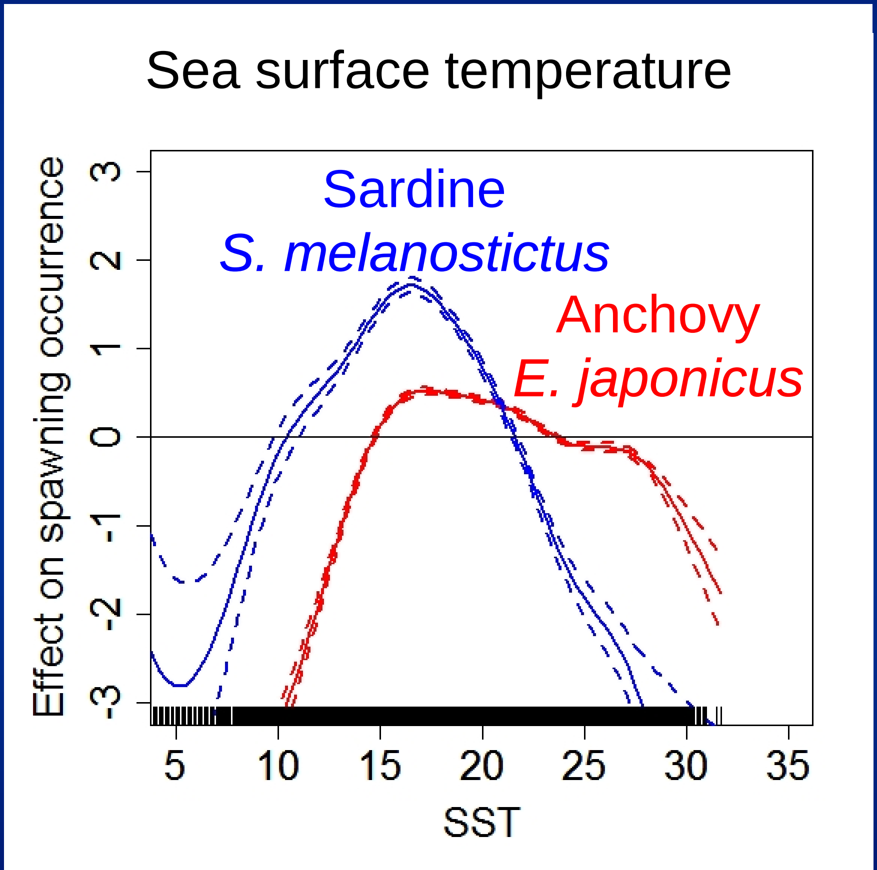
α: an intercept term

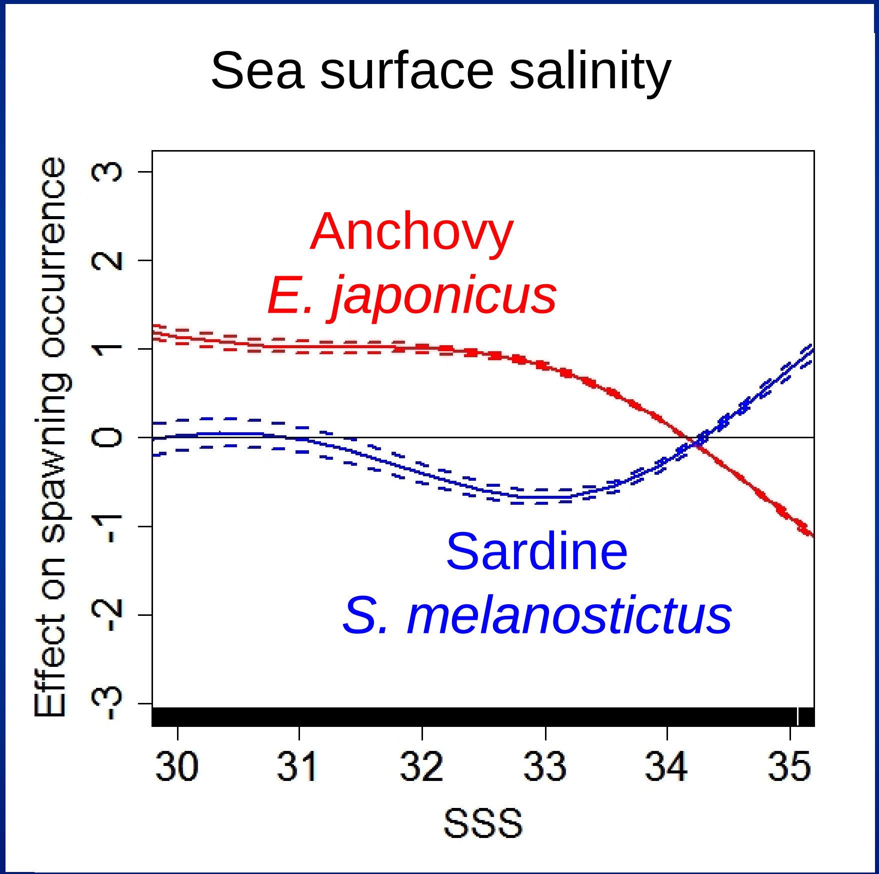
"*s*": an unique smooth term of thin plate regression spline base

Spawning responses

Kuroshio Current system

All areas and seasons included





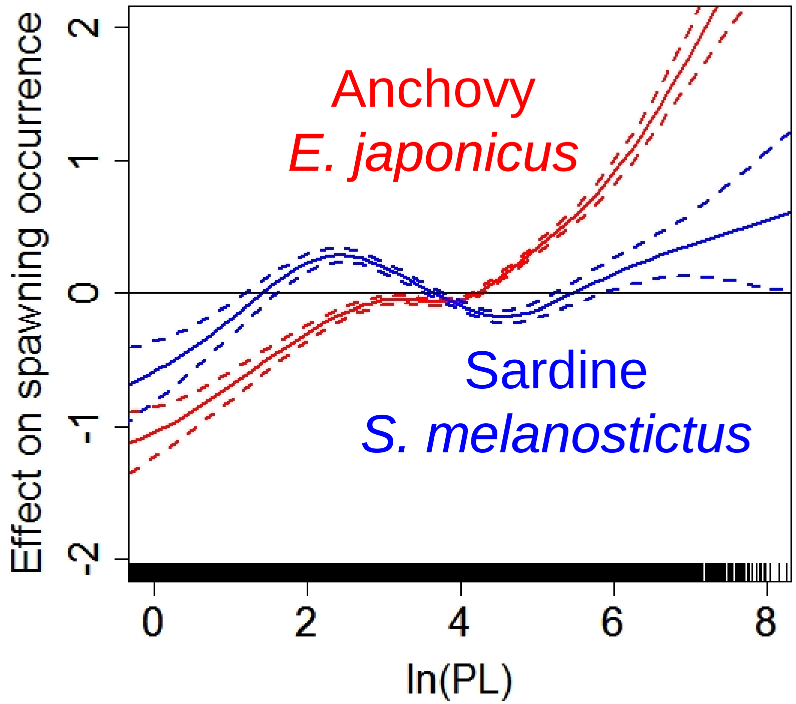
Effects of physical factors on spawning probability by the GAMs applied to egg occurrence data (1/0).

Spawning responses

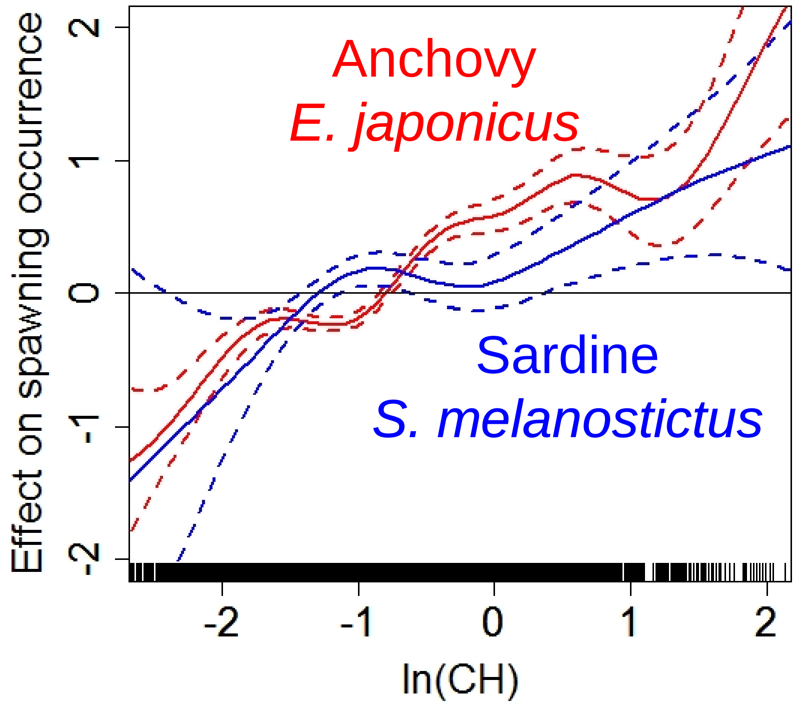
Kuroshio Current system

All areas and seasons included

Zooplankton volume



Chlorophyll-*a* concentration



Effects of biological factors on spawning probability by the GAMs applied to egg occurrence data (1/0).

Takasuka *et al*.

Income vs capital

Energy allocation strategies for reproduction are viewed as a continuum between "income" and "capital" breeders.

"Income breeders"	"Capital breeders"
➢ Expend energy recently acquired for reproduction During spawning, … • Spawn more with food • Keep feeding • Conditions do not dramatically change	➢ Expend energy stored over long periods for reproduction During spawning, … • Spawn irrespective of food • Stop feeding • Conditions dramatically decline

Anchovy (*E. japonicus*)	Sardine (*S. melanostictus*)
➢ Spawning probability increased monotonically with food availability.	➢ Spawning probability increased with food availability up to some extent but not at higher values.

On a continuum between "income" and "capital"

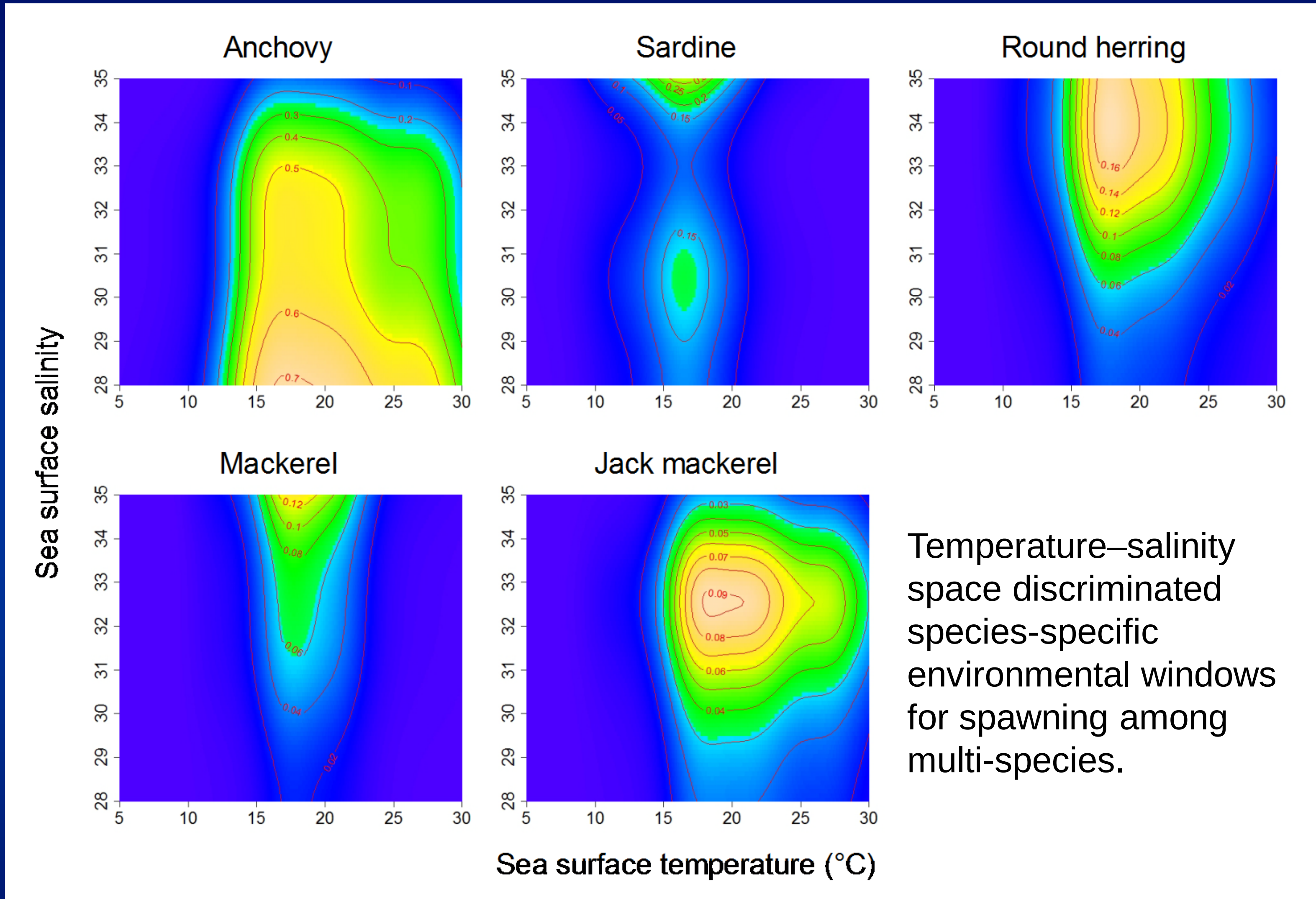
Income breeder ⟷ Capital breeder

Anchovy (*E. japonicus*)

Sardine sardine (*S. melanostictus*)

Takasuka *et al*.

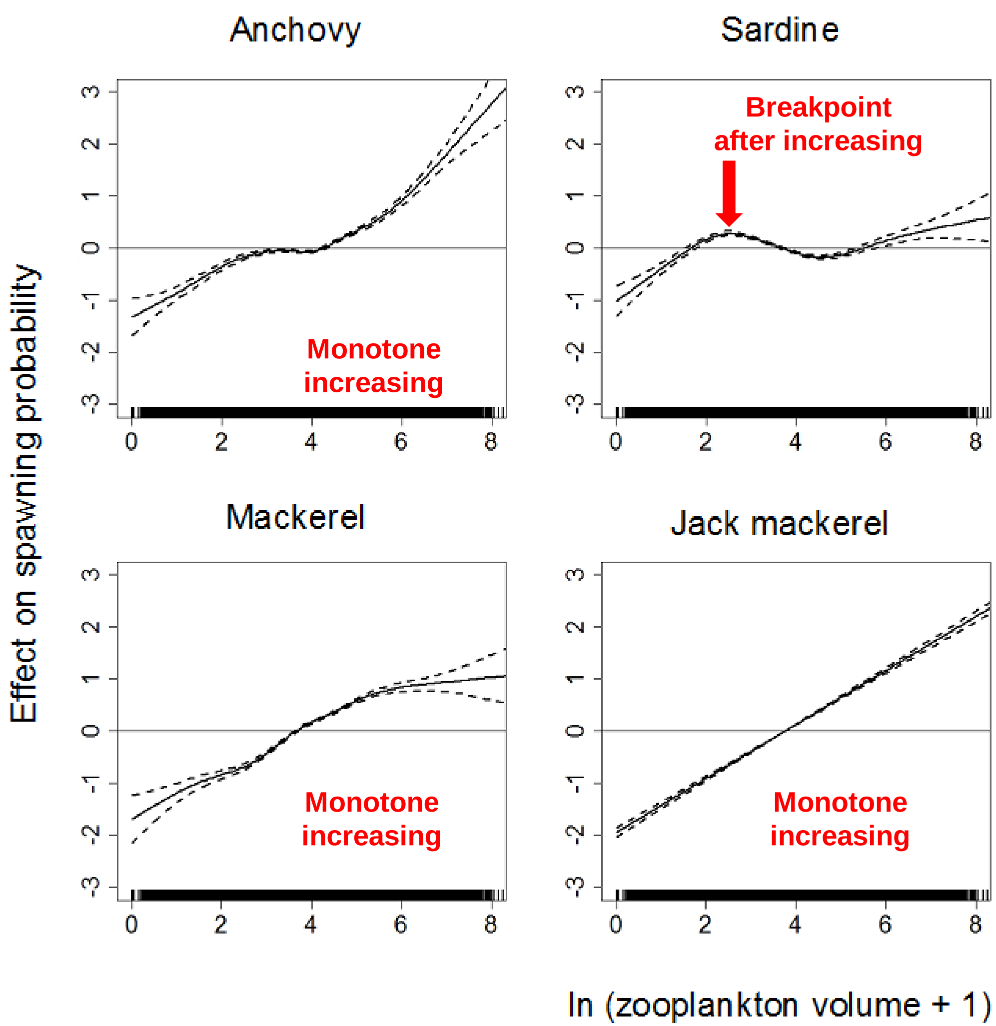
Temperature–salinity space



Temperature–salinity space discriminated species-specific environmental windows for spawning among multi-species.

Effects of physical factors on spawning probability by the GAMs applied to egg (or larval) occurrence data (1/0).

Energy allocation strategy



Small pelagic fish categorized by energy allocation strategy

Almost “income”:

- Anchovy
- Mackerel
- Jack mackerel

More “capital”:

- Sardine
- Round herring

Effects of zooplankton volume on spawning probability by the GAMs applied to egg occurrence data (1/0).

Summary & Future

Summary

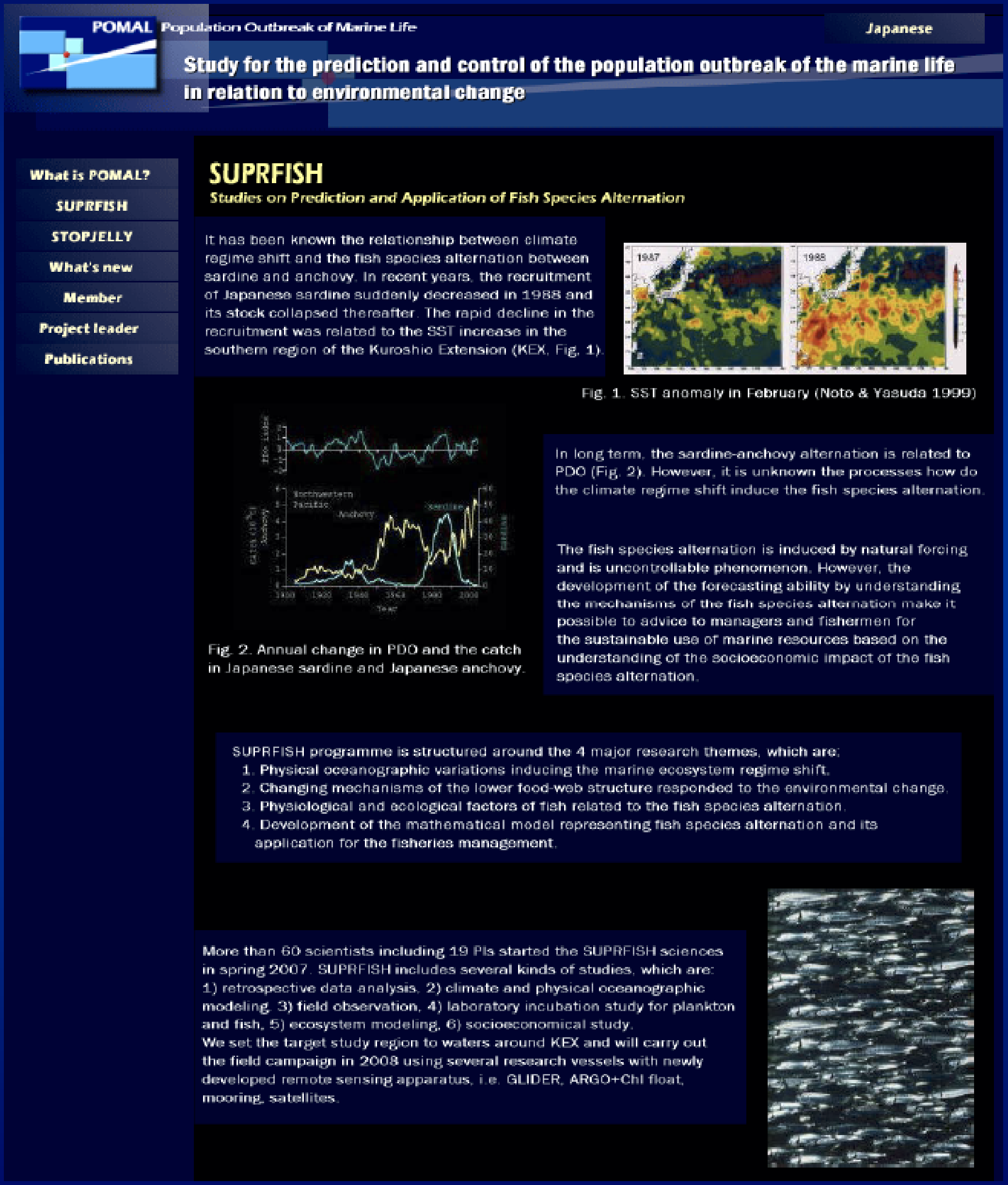
1. How dramatically environmental variability could regulate survival probability of small pelagic fish
   - Vital parameters serve as an amplifier linking environmental variability to dramatic survival variability.
2. How differently the similar environmental condition could affect the population dynamics of different species
   - Species-specific environmental windows would constitute a key to understand mechanisms of species alternations through differential climate effects on different species.

Future

- Different hypotheses should be synthesized in the future.
- Interspecific and intersystem comparisons
- Interdisciplinary collaboration

Takasuka *et al*.

SUPRFISH



POMAL Population Outbreak of Marine Life

Japanese

Study for the prediction and control of the population outbreak of the marine life in relation to environmental change

What is POMAL?
SUPRFISH
STOPJELLY
What's new
Member
Project leader
Publications

SUPRFISH

Studies on Prediction and Application of Fish Species Alternation

It has been known the relationship between climate regime shift and the fish species alternation between sardine and anchovy. In recent years, the recruitment of Japanese sardine suddenly decreased in 1988 and its stock collapsed thereafter. The rapid decline in the recruitment was related to the SST increase in the southern region of the Kuroshio Extension (KEX, Fig. 1).

Fig. 1. SST anomaly in February (Noto & Yasuda 1999)

In long term, the sardine-anchovy alternation is related to PDO (Fig. 2). However, it is unknown the processes how do the climate regime shift induce the fish species alternation.

Fig. 2. Annual change in PDO and the catch in Japanese sardine and Japanese anchovy.

The fish species alternation is induced by natural forcing and is uncontrollable phenomenon. However, the development of the forecasting ability by understanding the mechanisms of the fish species alternation make it possible to advice to managers and fishermen for the sustainable use of marine resources based on the understanding of the socioeconomic impact of the fish species alternation.

SUPRFISH programme is structured around the 4 major research themes, which are:
1. Physical oceanographic variations inducing the marine ecosystem regime shift.
2. Changing mechanisms of the lower food-web structure responded to the environmental change.
3. Physiological and ecological factors of fish related to the fish species alternation.
4. Development of the mathematical model representing fish species alternation and its application for the fisheries management.

More than 60 scientists including 19 PIs started the SUPRFISH sciences in spring 2007. SUPRFISH includes several kinds of studies, which are: 1) retrospective data analysis, 2) climate and physical oceanographic modeling, 3) field observation, 4) laboratory incubation study for plankton and fish, 5) ecosystem modeling, 6) socioeconomical study. We set the target study region to waters around KEX and will carry out the field campaign in 2008 using several research vessels with newly developed remote sensing apparatus, i.e. GLIDER, ARGO+Chl float, mooring, satellites.

Studies on Prediction and Application of Fish Species Alternation (SUPRFISH)
Leader: Saito, H. (FRA)
Period: 2007–2012

- Interdisciplinary project including 60 scientists
- 4 major themes

1. Physical oceanographic variations
2. Lower food-web structure
3. Physiological and ecological factors of fish
4. Modeling approaches to species alternations and fisheries management.

Upcoming ICES/PICES Symposium

FACTS - Forage Fish Interactions

Forage fish interactions: Creating the tools for ecosystem based management of marine resources

November 12–14, 2011, Nantes, France

Conveners: Stefan Neuenfeldt (DK), Myron Peck (DE), Tim Essington (US), Niels Vestergaard (DK), and Vladimir Radchenko (RU)

The overall key note will be given by Jake Rice, Canada, on Challenges and Opportunities for forage fish management in the first half of the 21st century. Five theme sessions will be convened that will open with an invited, keynote presentation:

Climatic and biotic mechanism forcing on forage fish population recruitment
(Key note: Akinori Takasuka, Japan)

Post recruitment predator-prey dynamics in ecosystems world-wide
(Key note: Geir Huse, Norway)

Linking biology and economics
(Key note: Røgnvaldur Hanesson, Norway)

Ecosystem-based management
(Key note: Jason Link, USA)

Comparisons between ecosystems and generic properties
(Key note: Jeremy Collie, USA)

http://www.facts-project.eu/Symposium2012.aspx

FACTS
Forage Fish Interactions

The FACTS project has received funding from the European Community's Seventh Framework Programme

SEVENTH FRAMEWORK PROGRAMME