Lecture for SOI
Advanced topics for Marine Science 2007

Floating eggs of marine fish -the size, buoyancy, and rising speed

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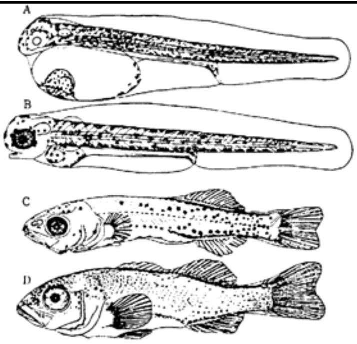
13 December 2007



Larva of Japanese sea bass (after Mito 1957)

図 54·3 スズキの稚仔魚（水戸，1957）
A：全長 4.5mm B：5.17mm C：13.7mm D：25.9mm

Dec 13, 2007 16:20-17:50(Marine Environmental Study)

Floating eggs of marine fish -the size, buoyancy, and rising speed

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Understanding survival and mortality of fish in the early life stages has been a fundamental issue in biology and a central problem in fisheries oceanographic study for more than a century. It has been argued that most marine fishes begin life as an egg that floats in the sea, and, during their evolutionary history, the early life of fishes has surely been shaped to ensure the "continued existence of species" by the sheer pressure of natural selection, and stated that a fish to survive must deal with and exploit its physical and biological environments. However, although we are now in the 21st Century, there still remains a lot to be made scientifically clear in the early life of fishes. In the present lecture, I will talk about fundamental issues in the isolated floating eggs of marine fish, which many pelagic species spawn in thousands, millions, or sometimes almost billions during a life of an individual female. The topics contain description and discussion on the egg size, buoyancy and rising speed. Measurements on the eggs naturally spawned in aquaculture systems are firstly introduced. Several examples of egg vertical distribution, accumulation and dispersion observed through field surveys will be shown to consider how the egg size and buoyancy are adaptive to survive in the pelagic environment.

Why study fish eggs and larvae？(1)

Drastic decrease in fish population

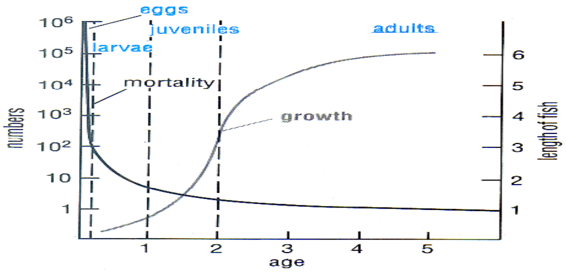
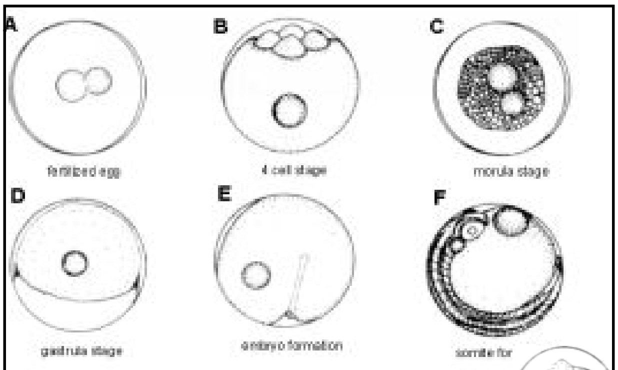


Figure 6.11 Idealized population mortality and individual growth curves for a species of teleost fish during its life cycle from egg to adult. Arbitrary units of age and length, and variable time intervals (indicated by dashed lines) for life stages.

(Figure after Lalli and Parsons 1997)



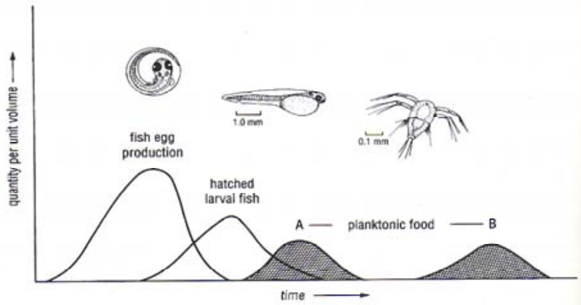
A typical isolated-floating egg of a marine fish
(after Ochiai and Tanaka 1986)

Why study fish eggs and larvae? (2) Match−Mismatch

Timing of larval copepoda production affects larval fish survival

Figure 6.12 The critical phase of larval fish survival requires that planktonic food (often copepod nauplii) must be present in the water at the time of hatching (e.g. at time A). If the food organisms occur later (e.g. at time B), all the fish larvae from one particular spawning will die from starvation. (Arbitrary units.)

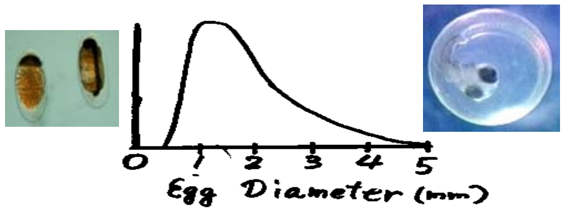
(Figure after Lalli and Parsons 1997)



To estimate early survival is crucial to forecast fish recruitment.

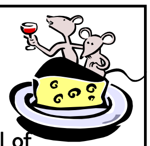
- Here, I would like to stress that we cannot understand nor forecast the recruitment process as a whole without knowing each link connecting each single phenomenon that comprises the whole process.

Size:
0.5-5 mm (diameter);
mostly around 1 mm



Size distribution of isolated floating eggs of marine fishes
(modified after Ahlstrom and Moser 1980)

After a wind blow (cause)...



1. dust increase in air
2. many people become blind
3. shamisen (a string instrument traditional of Japan) players increase
4. cat population decreases
5. rat population increases
6. many wooden buckets are gnawed
7. buckets are in demand

..., and finally,

coopers make profit!?... (effect)

after Japanese old saying:
" Wind causes coopers' profit."

Density (or specific gravity) of fish eggs

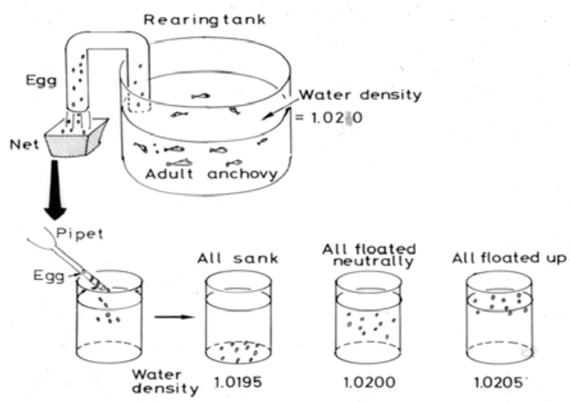
Density:
Buoyancy (specific gravity),

slightly less than medium seawater

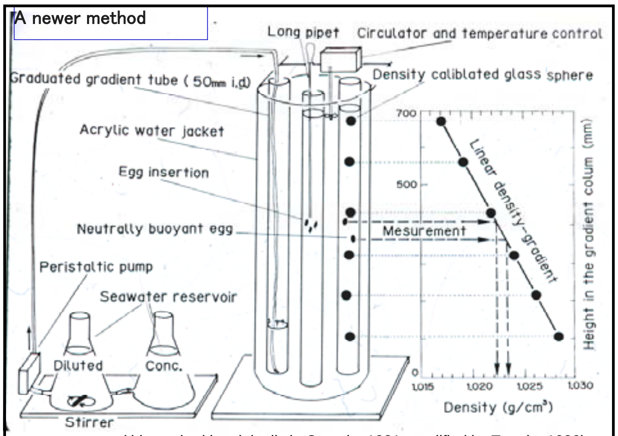
$\Delta\rho = 0.001 \sim 0.006 g/cm^3$

- Therefore, I am looking into the mechanisms governing dispersion and accumulation of fish eggs and larvae, keeping in mind that quantitative understanding of each sigle process in the mechanisms is of primary importance.
- The ultimate goal is to understand the recruitment mechanism.

Classic way to measure the egg density

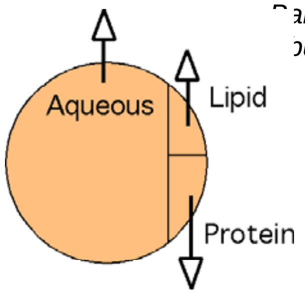


A newer method



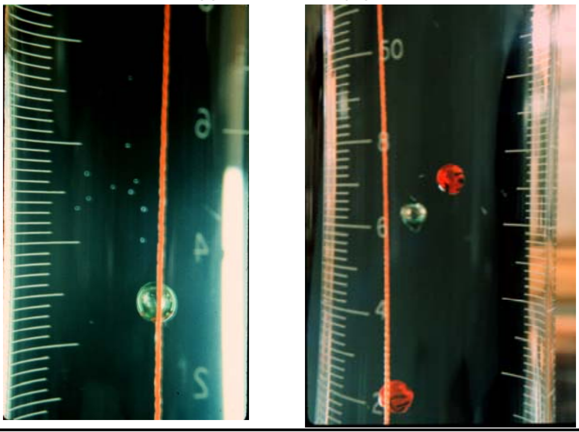
(this method is originally in Coombs 1981; modified by Tanaka 1990)

Balance of force affecting buoyancy in a fish egg



modified after Craik and Harvey (1984)

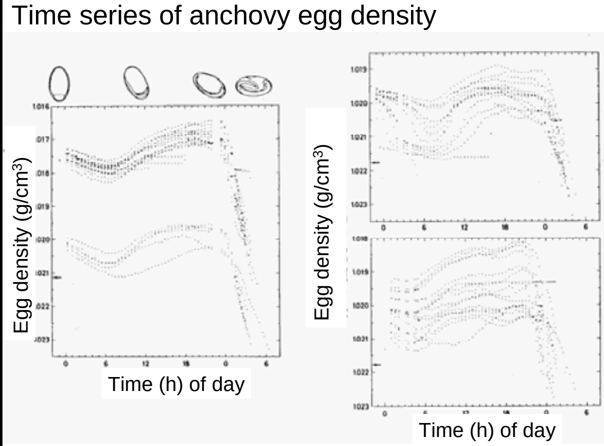
Eggs in the density gradient column



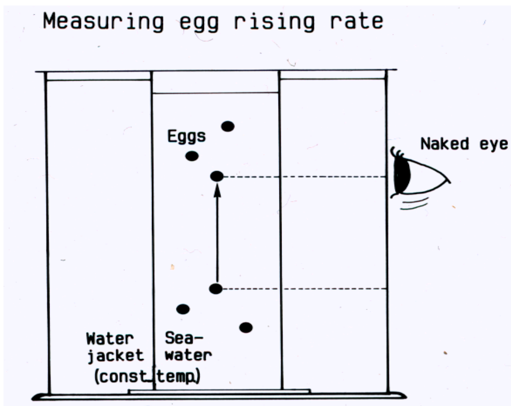
Rising rate (or speed) measurements

	マイワシ *Sardinops melanostictus*	カタクチイワシ *Engraulis japonicus*	クロダイ *Acanthopagrus schlegeli*	マダイ *Pagrus major*	イシダイ *Oplegnathus fasciatus*	オニオコゼ *Inimicus japonicus*
Mean diameter (mm)	1.50	.80 *	.87	.89	.90	1.34
Rising rate (mm/s)	1.4	.58	.42	.66	1.1	1.3
(range)	1.0-2.2	.21-.91	.24-.68	.42-.83	.6-1.4	.50-2.3

Time series of anchovy egg density



Measurement of rising speed



Stokes' law, which describes small particles' rising or sinking speed in fluid

$$w = \frac{(\rho_{egg} - \rho_{water}) \times g \times D \times D}{18 \times \eta}$$

ρ_{egg}: density of an egg (g/cm^3)
ρ_{water}: density of seawater (g/cm^3)
g: gravitational acceleration (cm/s^2)
D: diameter of an egg (cm)
η: viscosity of water (g cm^{-1} s^{-1})

Field reserach

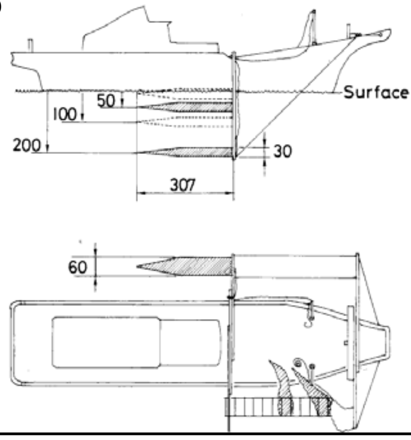
A boat rigged with the Ladder Net (Tanaka 1991)

Egg density measurements revealed:

1. Eggs are slightly (order of 0.001 g/cm^3) less dense than seawater.
2. The density varies during development. Significant increase in density before hatching was commonly observed.

How do theser features affect their distributions in the ocean?

Shiranami-maru
(digits are in cm)



Why study egg rising speed?

→To get a clue to understand how fish eggs and larvae distribute

Field observations

Lab observations

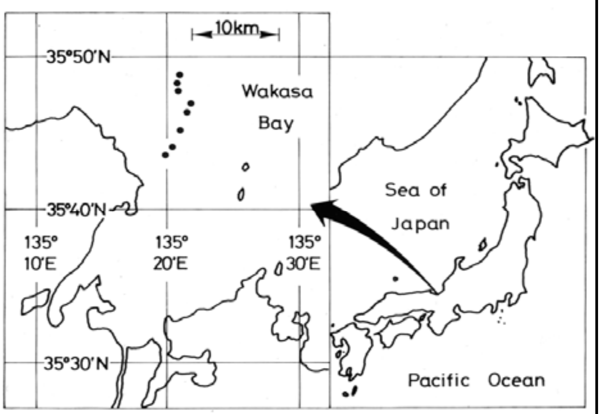
Distribution of organisms (such as fish eggs and larvae)

Distribution of physical properties (such as temperature, salinity, light, current, etc.)

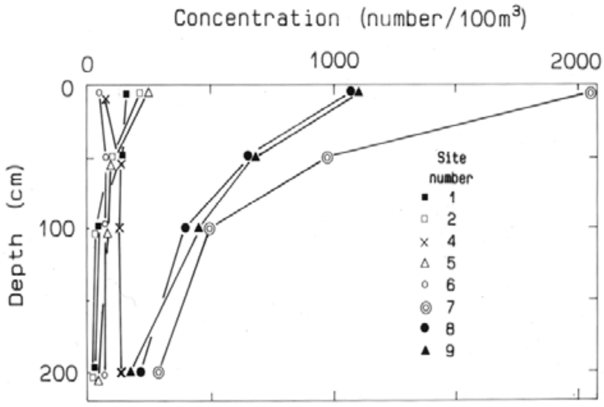
Measurements of rising speed

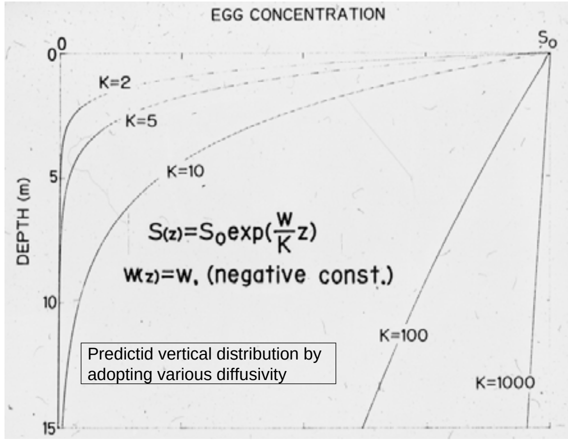
Inherent transport mechanisms?

Survey area



Vertical distribution of anchovy eggs
(actual measurements)





Predictid vertical distribution by adopting various diffusivity

one-dimensional model for vertical distribution
(simplest one)

$$K\frac{dS}{dz} - w(z)\,S = 0$$

K : vertical eddy diffusivity (cm^2/s)

S : egg concentration (inds./$100m^3$)

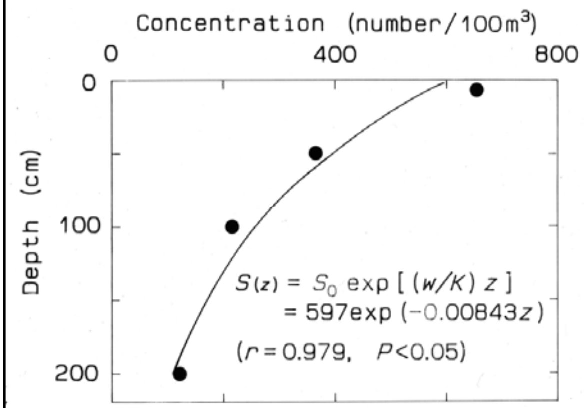
z : depth (cm)

w(z) : egg sinking velocity (cm/s) as a function of z

$$S(z)=S_0\exp[\frac{1}{K}\int w(z)dz]$$

S_0:egg concentration at z=0

Applying the model to the field- observed data



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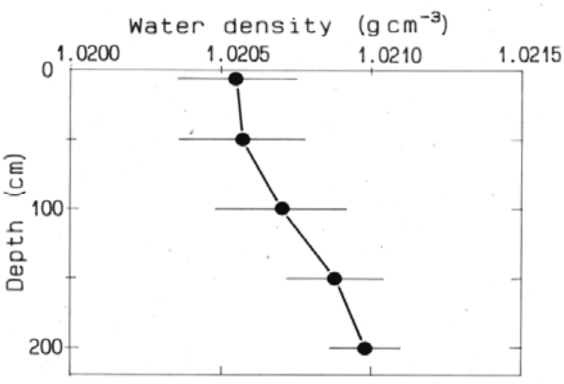
$$S(z)=S_0\exp[\frac{1}{K}\int w(z)dz]$$

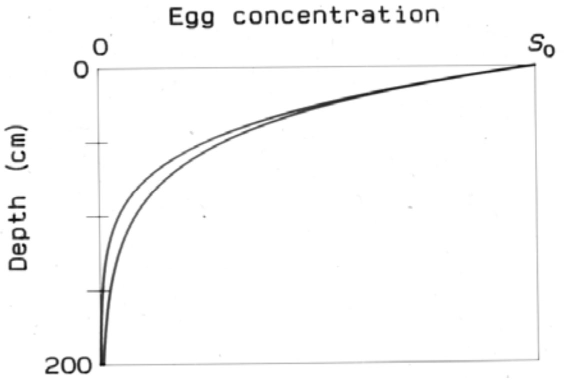
w(z) = w = const. (negative)

$$S(z)=S_0\exp(\frac{w}{K}z)$$

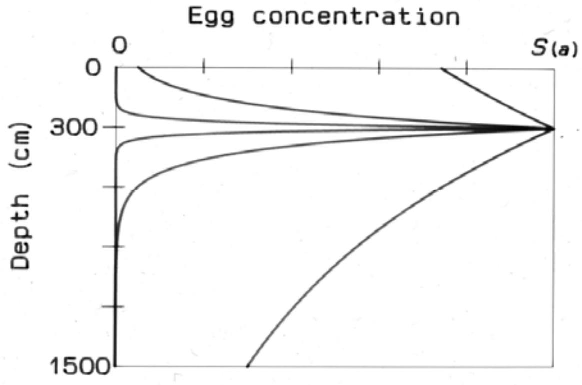
Vertical distribution of water density, showing actual state of stratification when the observation was done



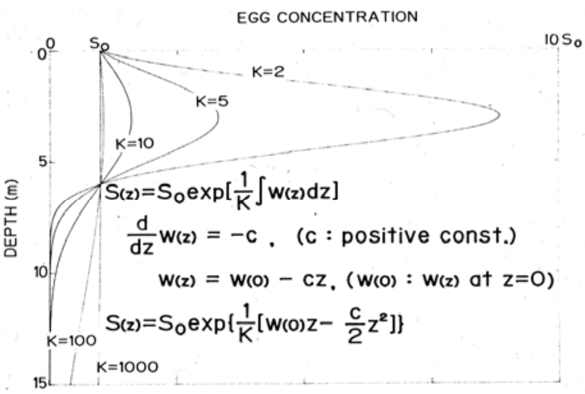
Model results considering the effect of actual stratification



Another model describing the mid^water accumulation (assuming the sinking/rising speeds are constant



Model prediction for the case of very strong stratification exists, so the eggs bocome neutrally buoyant underwater.



Konowedge on rising/sinking speed helps us understand the vertical distribution of the eggs.

Note :

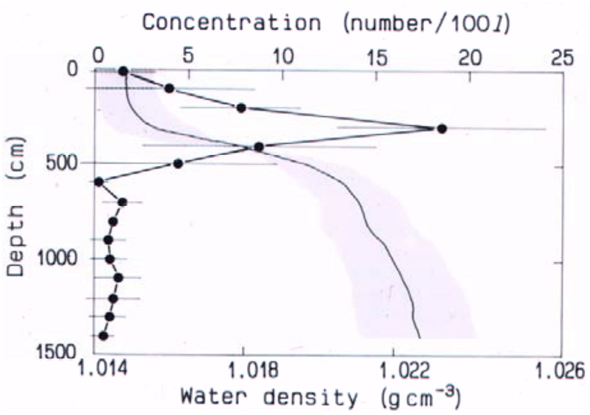
Measurements on the *in situ* vertical distributions of eggs showed accumulations of anchovy eggs at the seasurface or pycnocline.

These could be explained by using the quantitative information of

1) the buoyancy and rising rate of the eggs and

2) physical properties of the water column such as stability and vertical eddy diffusivity.

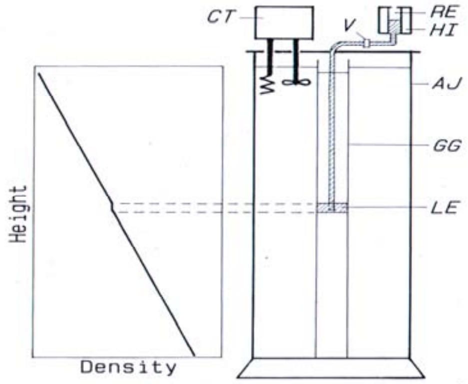
Actual observation of mid-water accumulation of eggs.

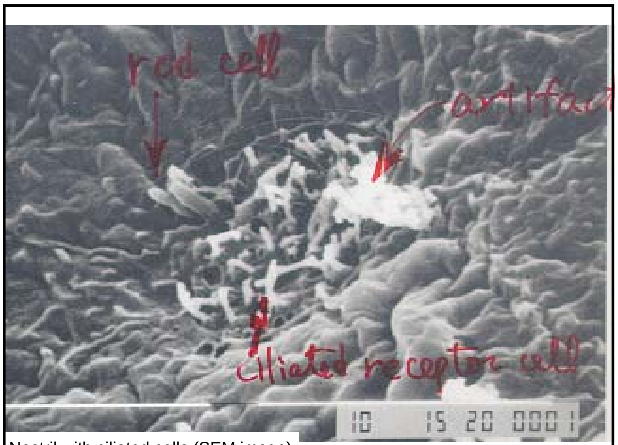


Only physics?

- Definitely not.

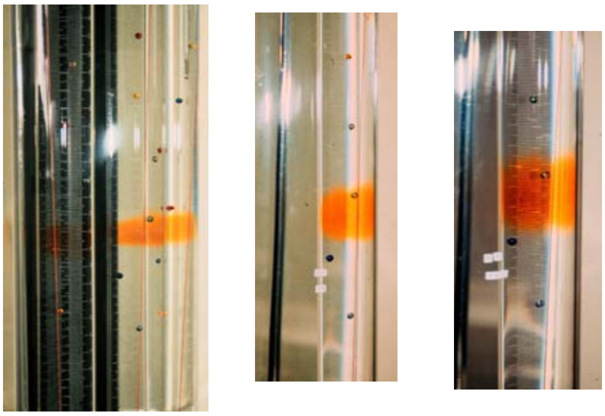
How biological processes work?



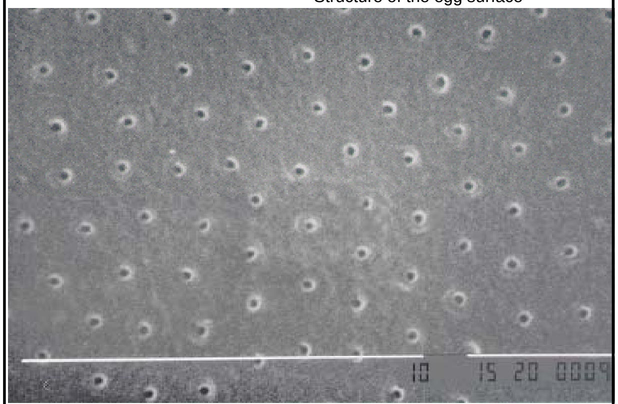


Nostril with ciliated cells (SEM image)

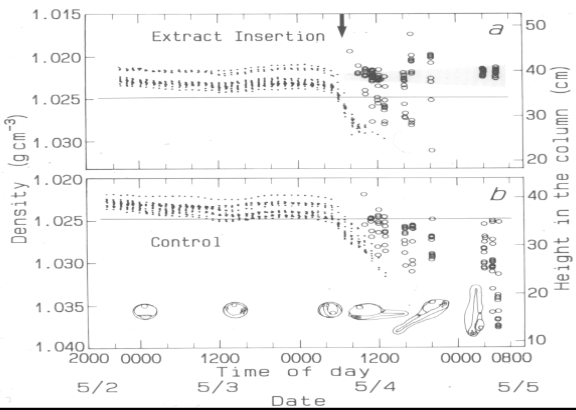
Thin layer of dye



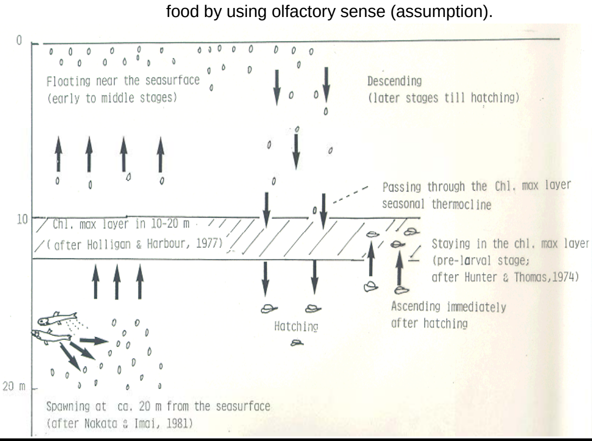
Structure of the egg surface



How red sea bream (*Pagrus major*) larvae accumulate in a layer of dense food (actual observation: after Tanaka et al., 1991).



Benefit of the larval behavior to accumulate in a layer of food by using olfactory sense (assumption).

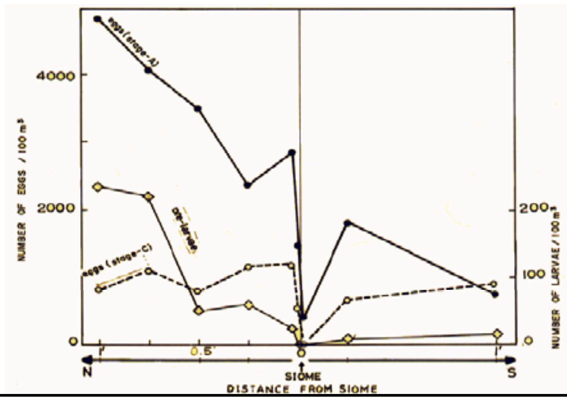


OK.
So, what happens in
horizontal processes?

Surface tow of plankton net

Seasurface slicks, where weak convergence is ongoing

Horizontal distributions of anchovvy eggs and larvae across the front
(Tanaka, unpublished)

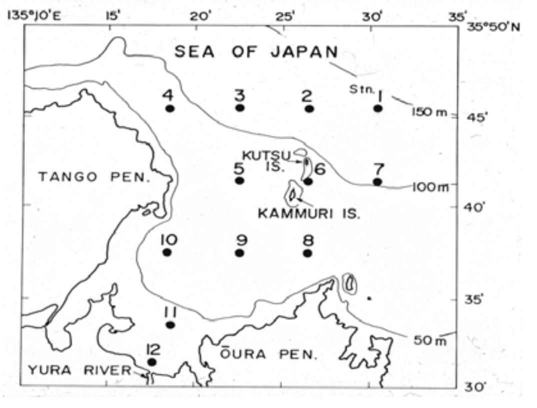


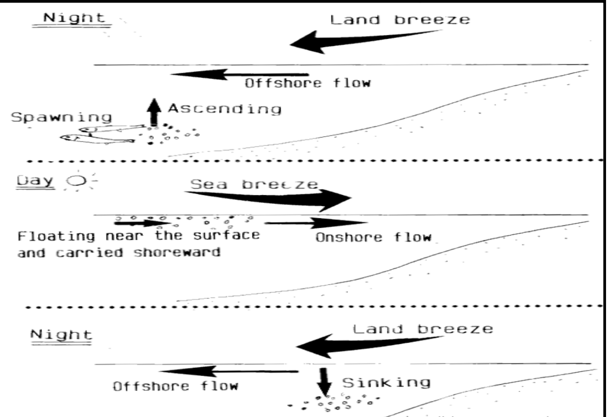
Oceanic front visually recognized.
See the marker float with a radar reflector

Front does not accumulate everything

- Fish eggs are not always so buoyant to remain in the surface against downwelling at convergence zones (or fronts).

Grid survey at Tango-sea, Wakasa Bay, Sea of Japan



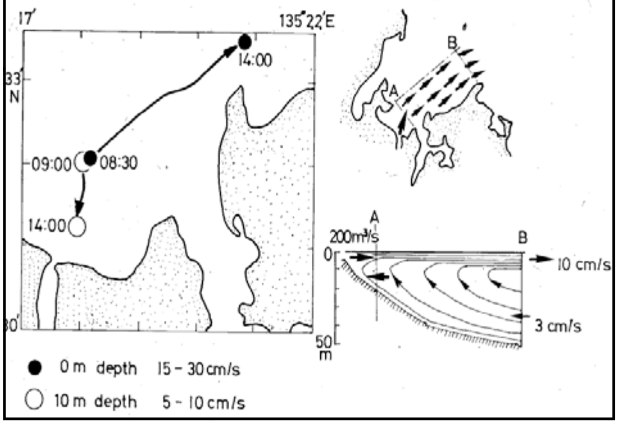


after Tanaka 1991

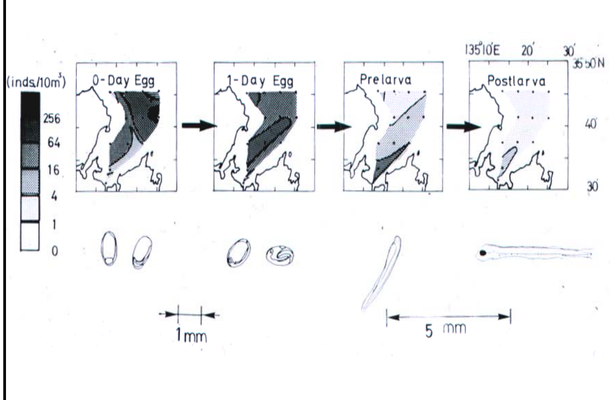
Possible transport due to sea-breaze and land-breaze

Eggs and larvae of Japanese anchovy *Engraulis japonicus*

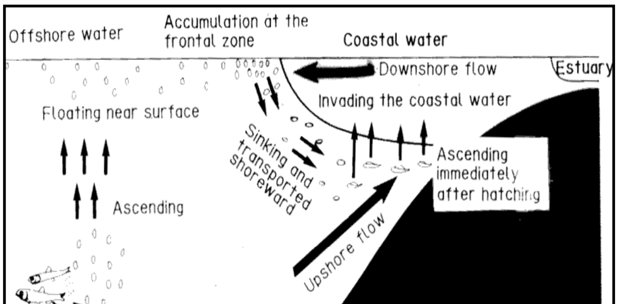
Estuarine circulation at Tango-sea



Stage-dependent horizontal distributions



after Tanaka 1991



Onshore transport mechanism?

(after Tanaka 1991)

Anchovy egg inherent mechanism to invade the coastal water from the offshore water

Additional slide: Embryonic development of Japanese sardine *Sadinops melanostictus* (from the archive of Ichthyology lab, TUMST).

Conclusions

**Dispersion of Ichthyoplankton are not always passive.
It is true even for eggs.**

They change buyaoncy during development, and may smell to choose where to stay, and maybe where to go.

Question 1

Estimate the number of fishes that recruit from a single individual of adult female under the following conditions:

- an adult female fish of 5 kg in weight spawns 500 g of eggs,
- diameter of each egg is 1 mm,
- 0.001% of the eggs survive until recruit.

You may roughly approximate $\pi = 3$ for calculation.

In addition, please imagine what would be the case if the survival rate was 0.01% or 0.0001%.

- For environmental studies such as fisheries science, multi-disciplinary studies should be done.

  ...not only fish, not only physics...

- In such study, quantitative information is always important.
- Efforts to synthesize such info from various aspects are required.

End

Question 2

Estimate (to two significant figures) the rising speed of a fish egg under the conditions given below:

- eggs are spherical, with diameter of 1.0 mm,
- egg density is 1.020 g cm^{-3},
- seawater density is 1.025 g cm^{-3},
- seawater viscosity is 0.010 g cm^{-1} s^{-1} (at 20° C),
- gravitational acceleration is 980 cm s^{-2}.

Please also think about the case when seawater temperature is 10° C or 30° C.

----- That's all -----