Oct. 29, 2026
PICES-2026 Annual Meeting

# Determinants of starvation tolerance in reared Japanese anchovy larvae: relative roles of somatic size, age, and growth rate

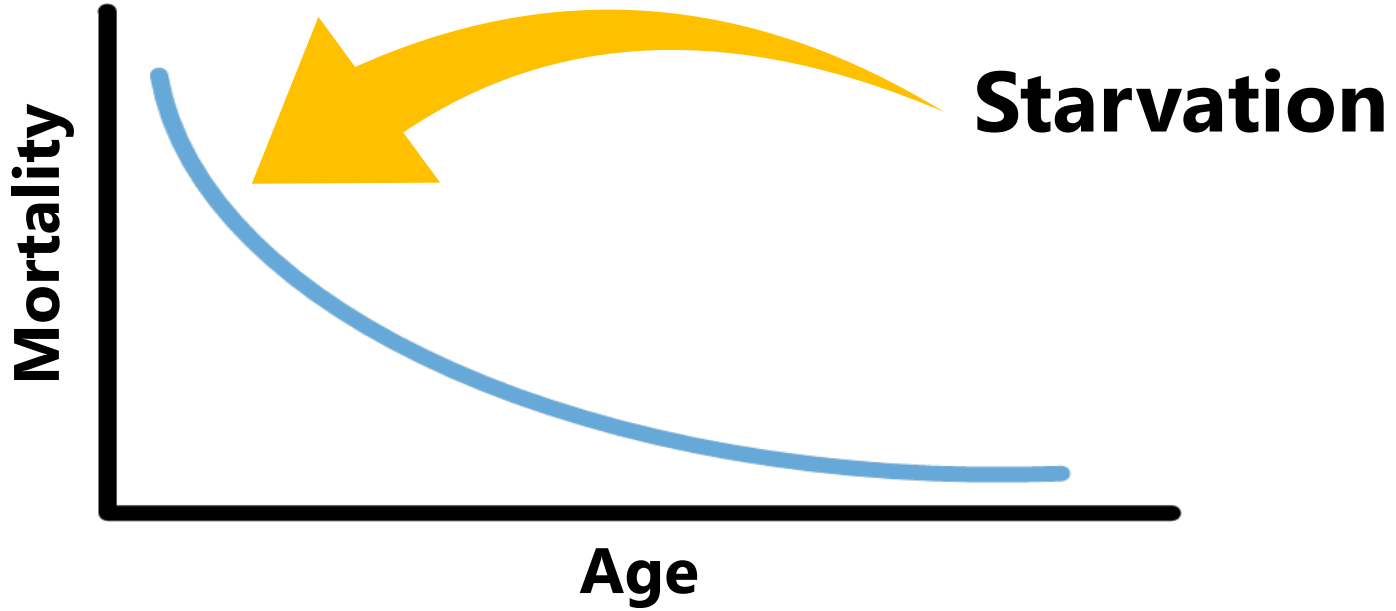
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# Introduction Larval survival

"Critical period" hypothesis

Survival through the first feeding determines year-class strength through starvation (Hjort 1914).




**What characteristics determine larval survival is unclear.**

# Introduction Growth–survival paradigm

Faster-growing larvae have higher probabilities of survival (Anderson 1988).

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



**Somatic size**

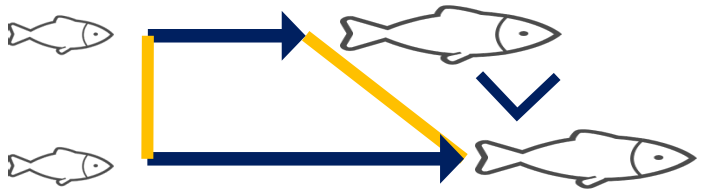
**Growth-selective predation**
(Takasuka et al. 2003, 2007)

**Fast growth** **Slow growth**



**Growth rate**

**Stage duration**
(Chambers & Leggett 1987; Houde 1987)



**Developmental stage**

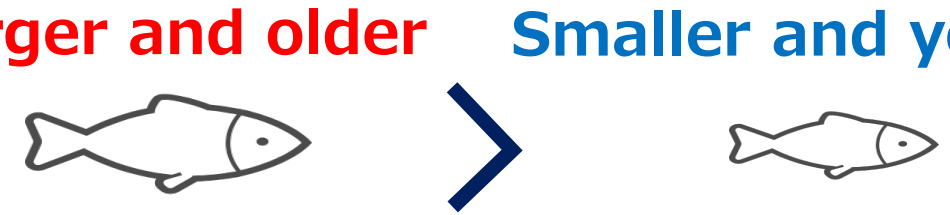
**Growth advantage is divided into several factors.**

# Introduction Growth and starvation tolerance

Growth factors

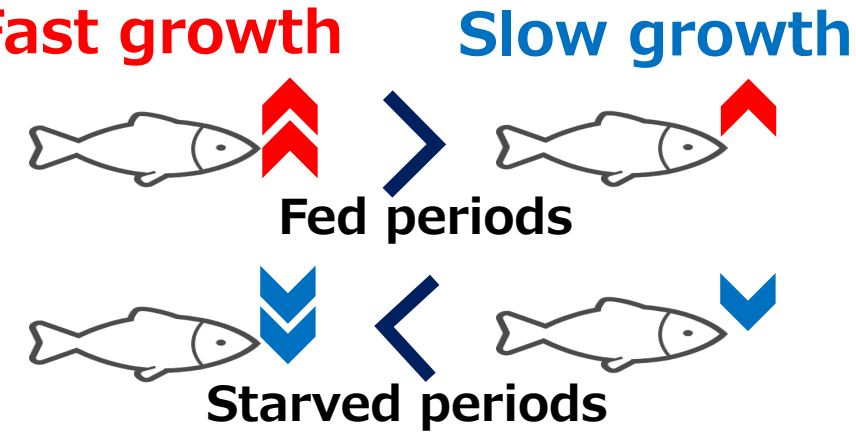
## Somatic size and age

Larger and older larvae and juveniles have higher starvation tolerance (Tanda 1989; Umeda 1996).




## Growth rate

Faster-growing juveniles lose more body mass during food deprivation (Dupont-Prinet et al. 2010).




**How do age, somatic size and growth rate relate to starvation tolerance at the individual level?**

# Introduction Biases in field-collected larvae

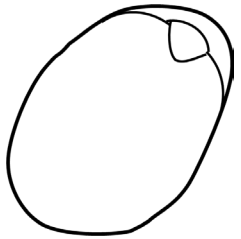
Environmental / maternal factors

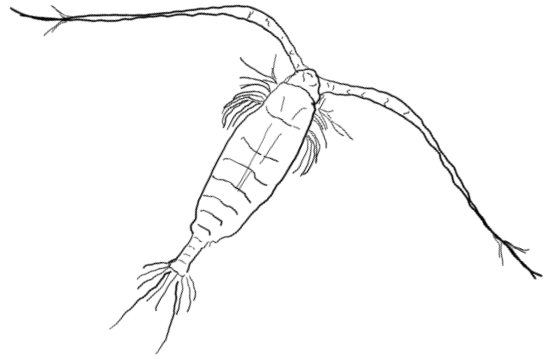
**Temperature** (Imai & Tanaka 1996)

**Prey condition** (Umeda 1996)

**Maternal effect** (Yoneda et al. 2022)







Field-collected larvae experience different environmental histories and originate from different spawning batches.

**This variation makes it difficult to interpret starvation tolerance in field-collected larvae.**

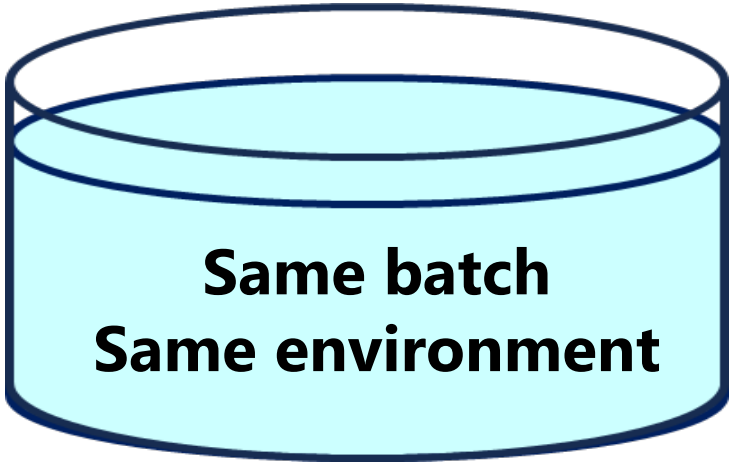
# Introduction

- Laboratory rearing experiments

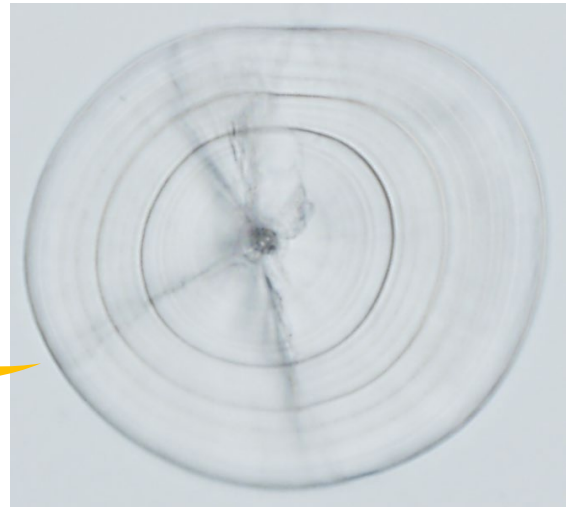
⇒ Comparisons among larvae from the same spawning batch reared under common conditions.

- Otolith increments provide information on growth histories (Campana & Neilson 1985).

⇒ Estimation of somatic size and growth rate of starved larvae.




**Growth histories**



# Introduction Japanese anchovy

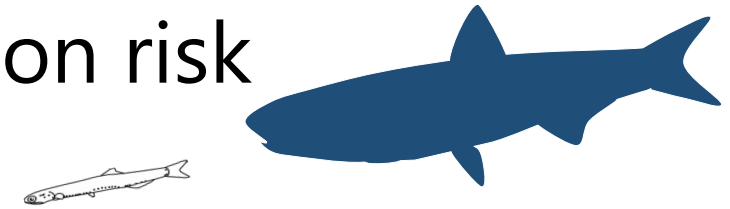
Japanese anchovy (*Engraulis japonicus*) larvae

**24 days old**



- Relationships between growth and predation risk

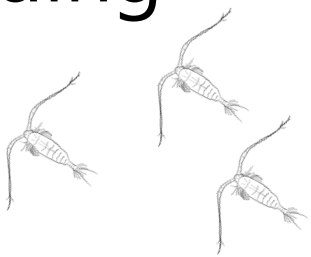
  (Takasuka et al. 2003, 2007)

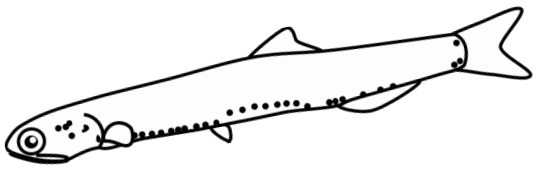




- Relationships between growth and feeding

  (Togoshi et al. 2024; Tanaka et al. 2026)





**The relationship between growth and starvation tolerance remains insufficiently understood.**

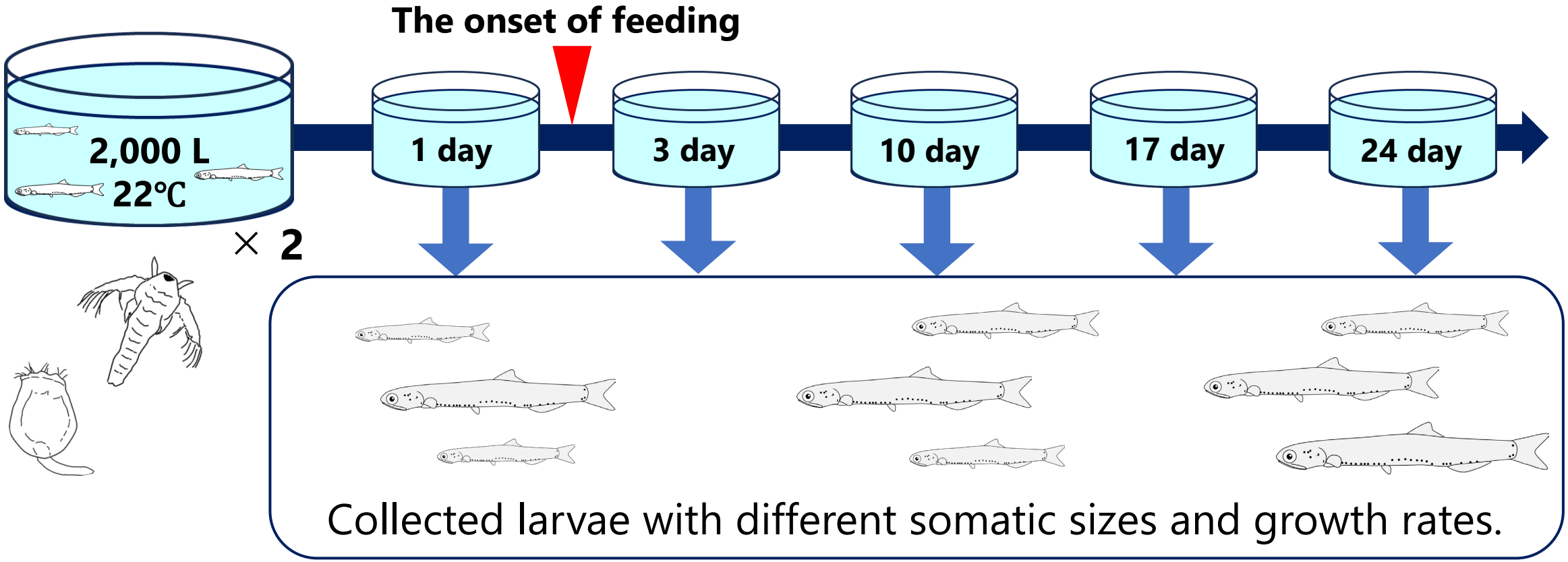
# Objectives

**Examining the relationship between growth and starvation tolerance in Japanese anchovy larvae by rearing experiments.**

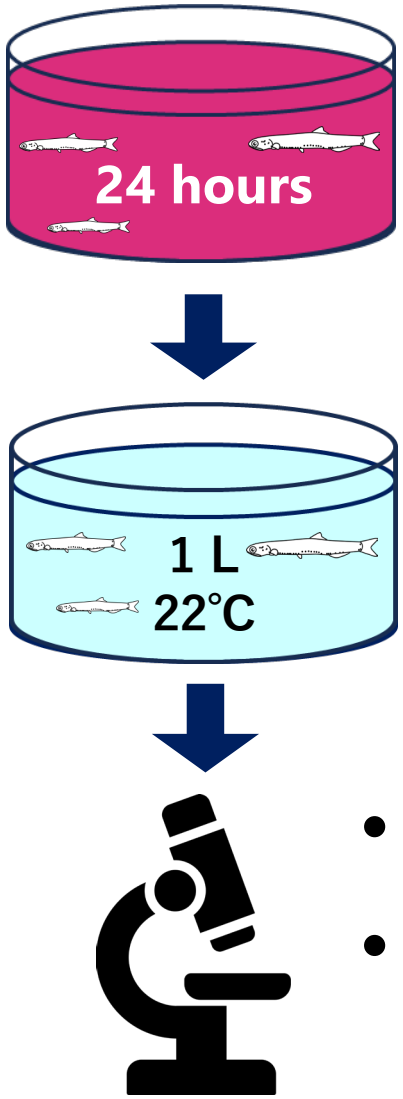


# Methods Rearing

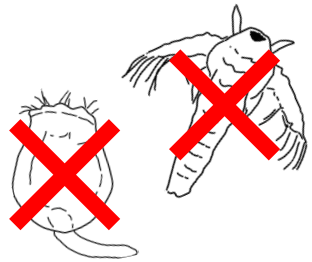
- Japanese anchovy (*Engraulis japonicus*) larvae
- Eggs obtained from captive broodstock



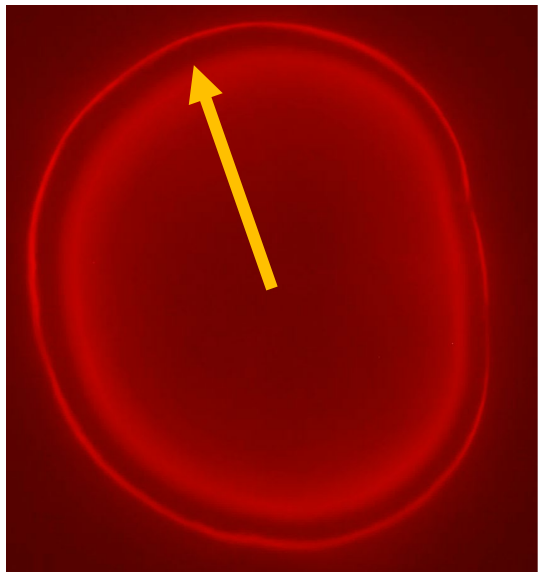
# Methods Starvation experiments




- Otoliths were stained with Alizarin complexone (ALC).

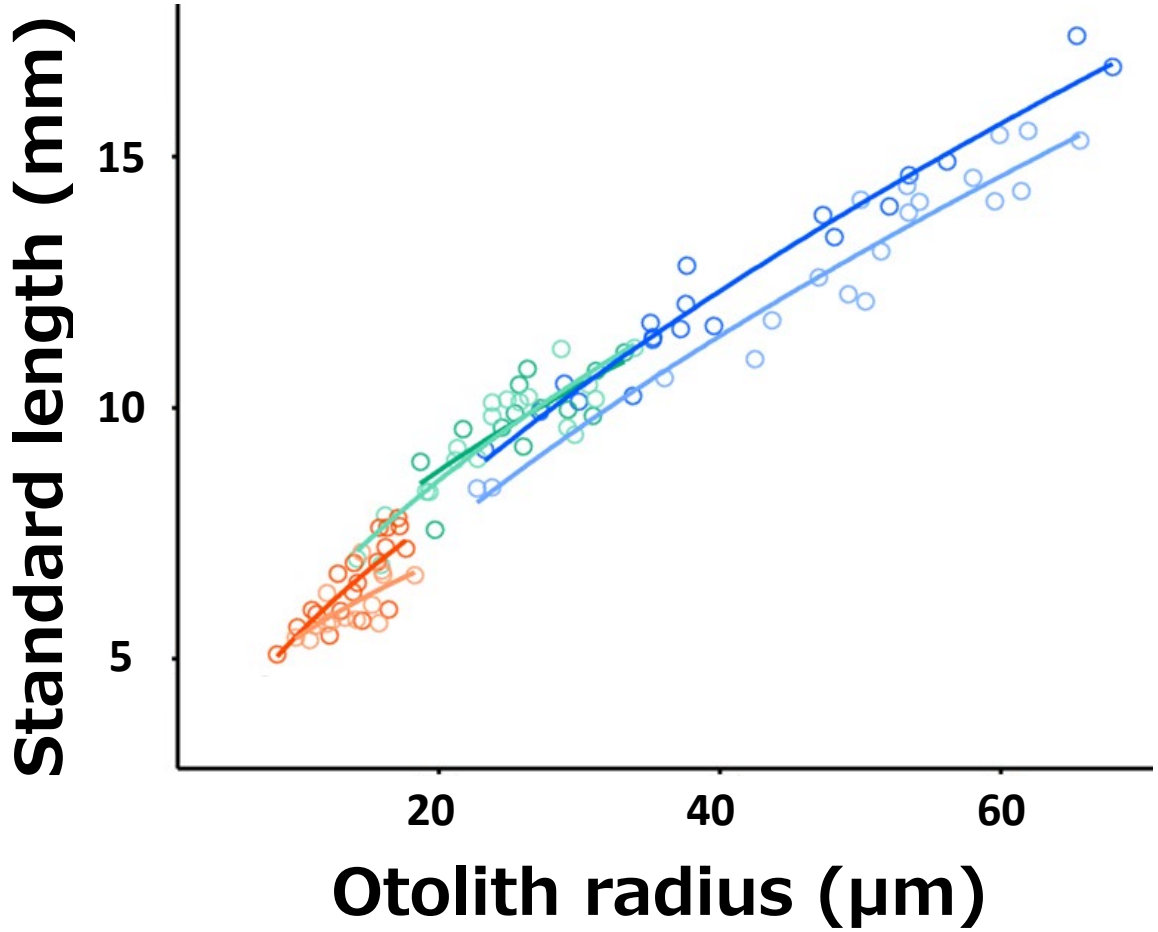


- Reared without food
- Survival duration was recorded.



- Otoliths were extracted from larvae.
- The distance from the core to the ALC-labeled increment was measured.

# Methods Otolith–somatic size relationships




Age. tank

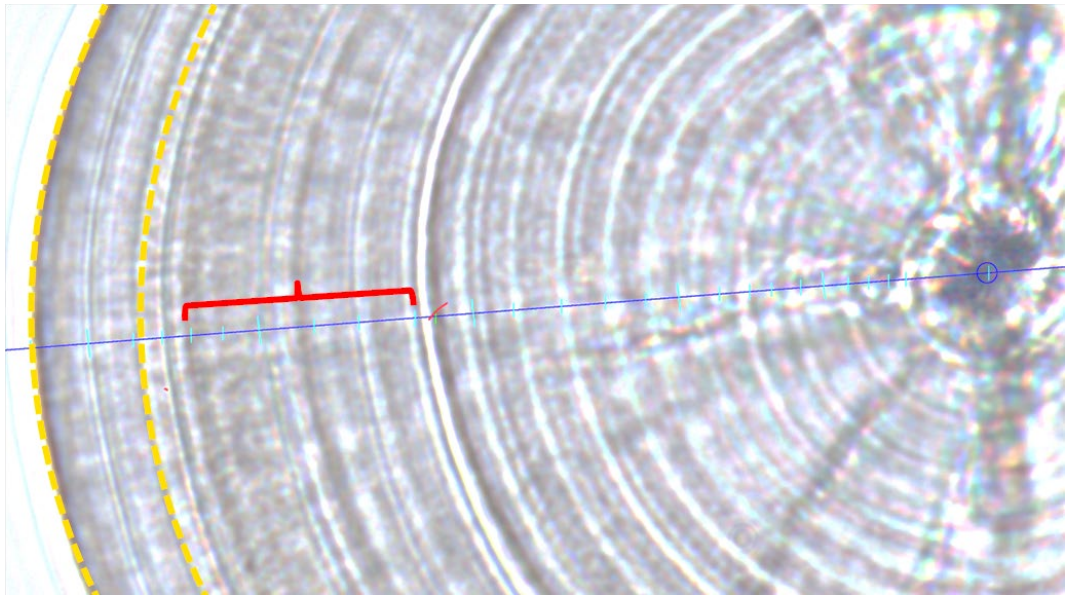
- 10.A $y = 1.6888 \times x^{0.5132}$ $R^2 = 0.657$
- 10.B $y = 2.4205 \times x^{0.3521}$ $R^2 = 0.483$
- 17.A $y = 2.3641 \times x^{0.4370}$ $R^2 = 0.593$
- 17.B $y = 1.8066 \times x^{0.5194}$ $R^2 = 0.823$
- 24.A $y = 1.3961 \times x^{0.5904}$ $R^2 = 0.961$
- 24.B $y = 1.2273 \times x^{0.6050}$ $R^2 = 0.927$

- Standard lengths at the onset of starvation were estimated from these relationships (10, 17 and 24 days old).

# Methods Otolith microstructure

- Otoliths with clearly visible increments were measured. (17 and 24 days old)
- Proxy for recent growth rate:
  Mean otolith increment width (µm/day) over the 5 days before the starvation experiments

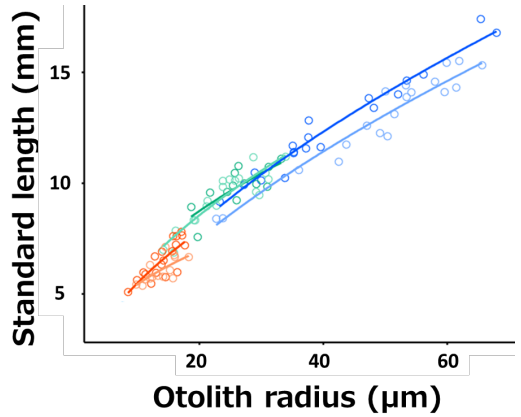


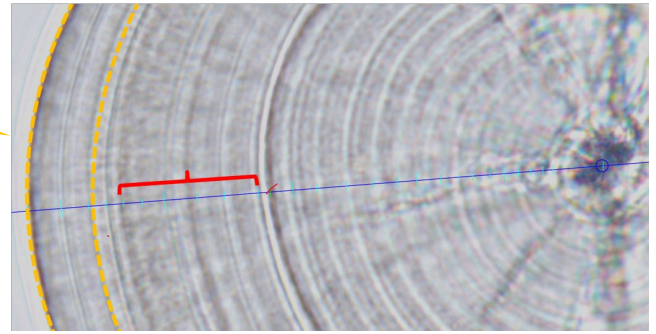


# Methods Statistical analysis

Generalized linear model (GLM)

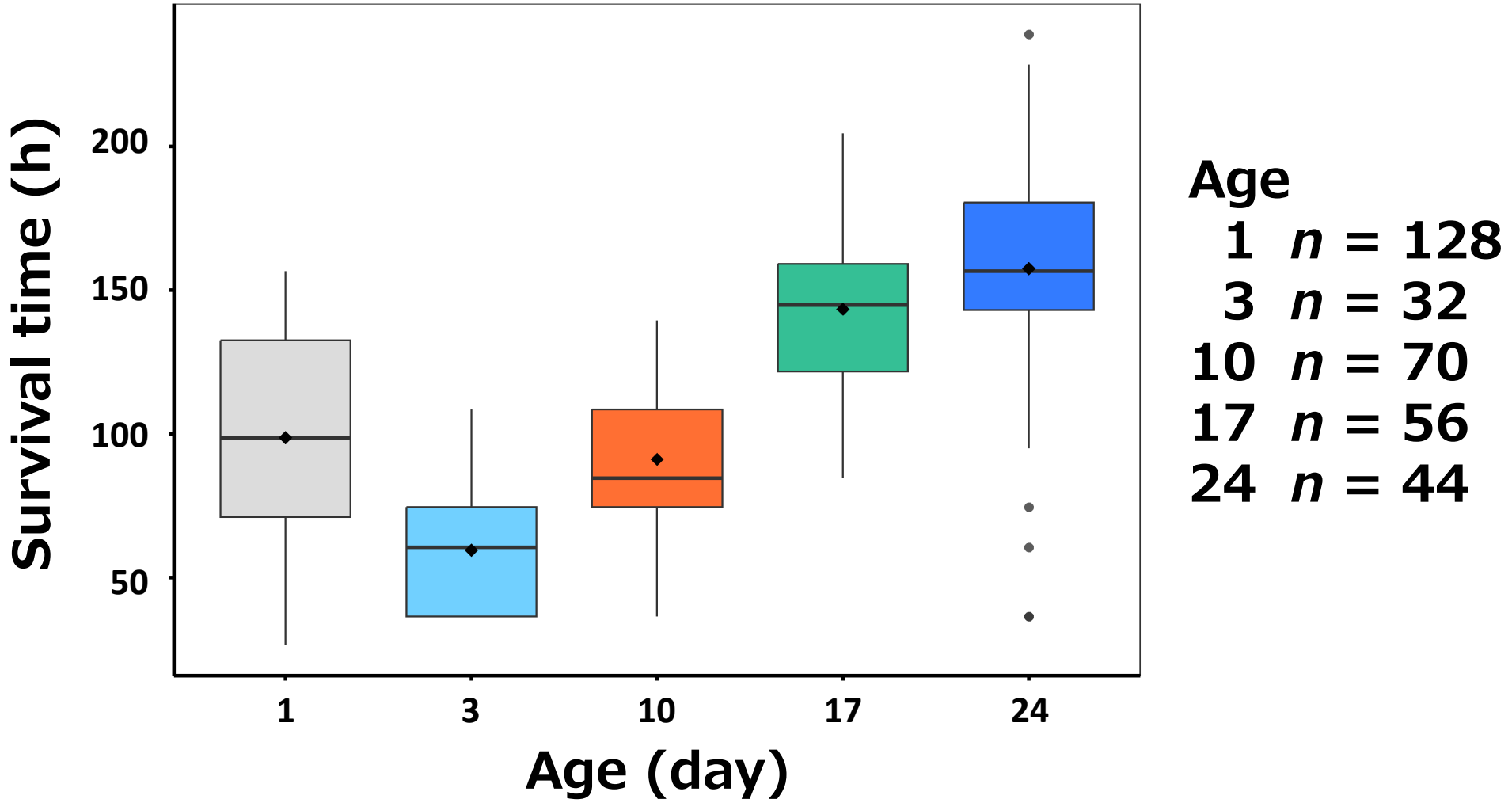
- Gamma (log link)
- Response variable: survival time (h)
- Explanatory variables: age (day)
  standard length (SL) (mm)
  recent growth rate residual
  tank



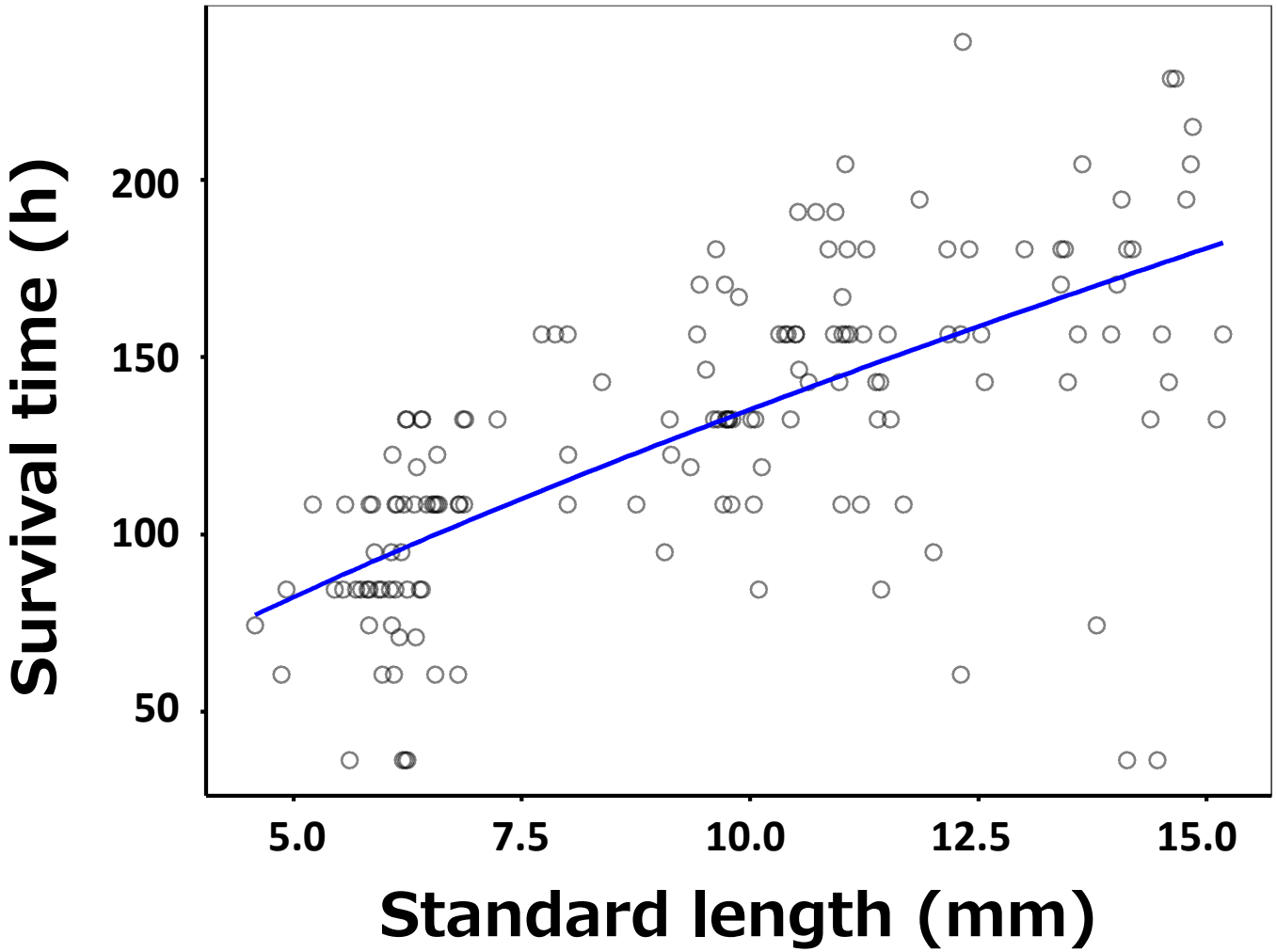
- Candidate models were compared using Akaike's Information Criterion (AIC).

# Results Age and starvation tolerance




Starvation tolerance generally increased with age.

# Results Somatic size and starvation tolerance




**10-24 days old**

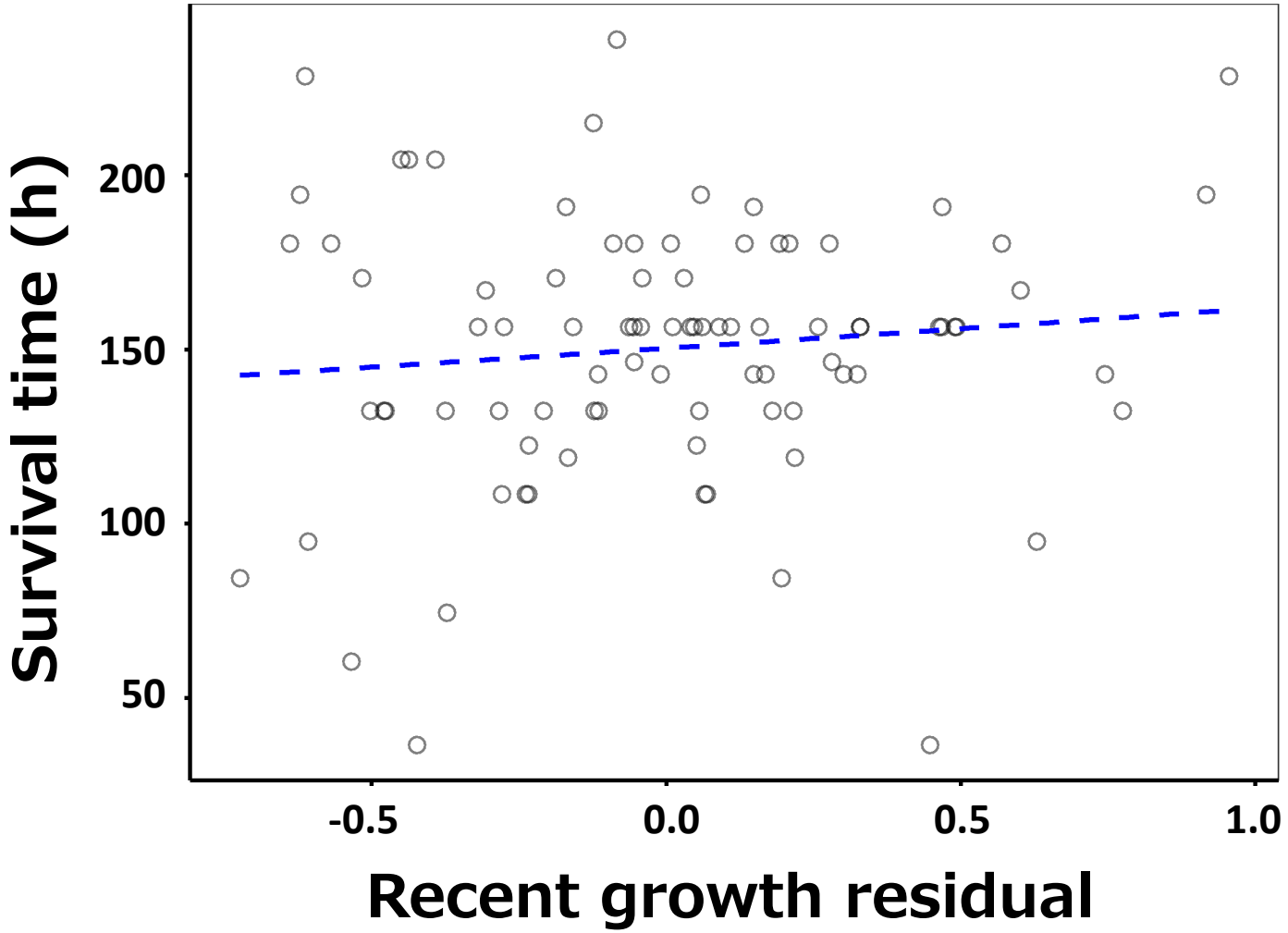
$y = 26.09 \times x^{0.715}$

$p < 0.001$

$n = 154$

Starvation tolerance was clearly associated with somatic size.

# Results Growth rate and starvation tolerance

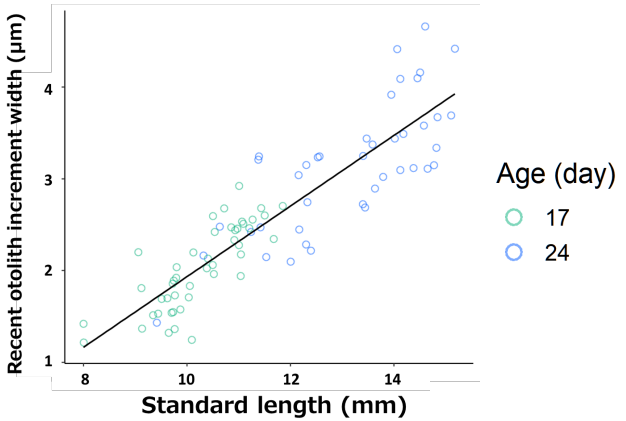



**17 and 24 days old**

***p* = 0.305**
***n* = 87**

SL fixed at its mean (11.62 mm)

The residuals corrected for SL

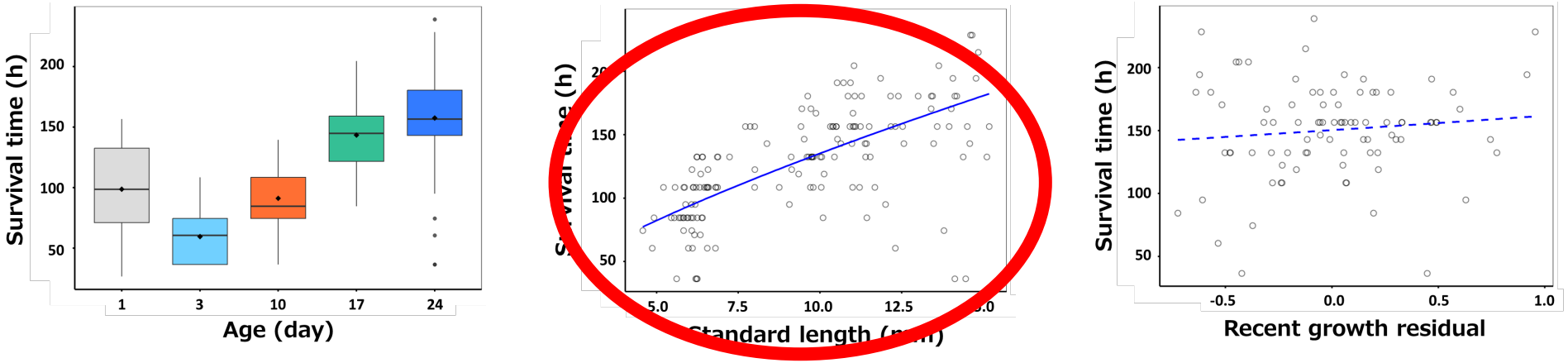



Starvation tolerance showed no clear relation with recent growth.

# Results GLM

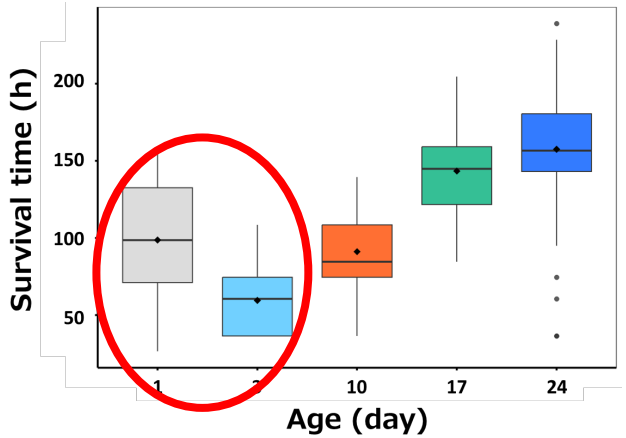
| models | AIC | ΔAIC |
|---|---|---|
| ln (SL) | 901.899 | 0.000 |
| ln (SL) + recent growth residual | 903.127 | 1.228 |
| ln (SL) + tank | 903.137 | 1.238 |
| ⋮ | ⋮ | ⋮ |

The SL-only model had the lowest AIC.




**Starvation tolerance was mainly explained by somatic size.**

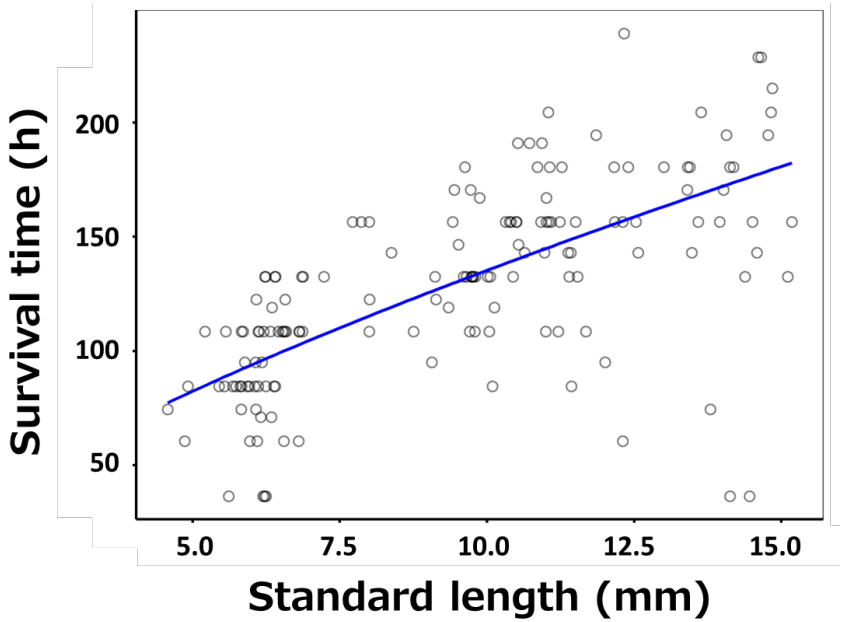
# Discussion Age and starvation tolerance




- Feeding larvae show greater swimming activity than larvae of the same age that have not yet started feeding (Fukuhara & Takao 1988).
  ⇒ The onset of feeding may increase energy consumption.

- Japanese anchovy larvae absorb their yolks in 2 or 3 days (Tsuji & Aoyama 1983).
  ⇒ Residual yolk may help the higher starvation tolerance.

# Discussion Somatic size and starvation tolerance



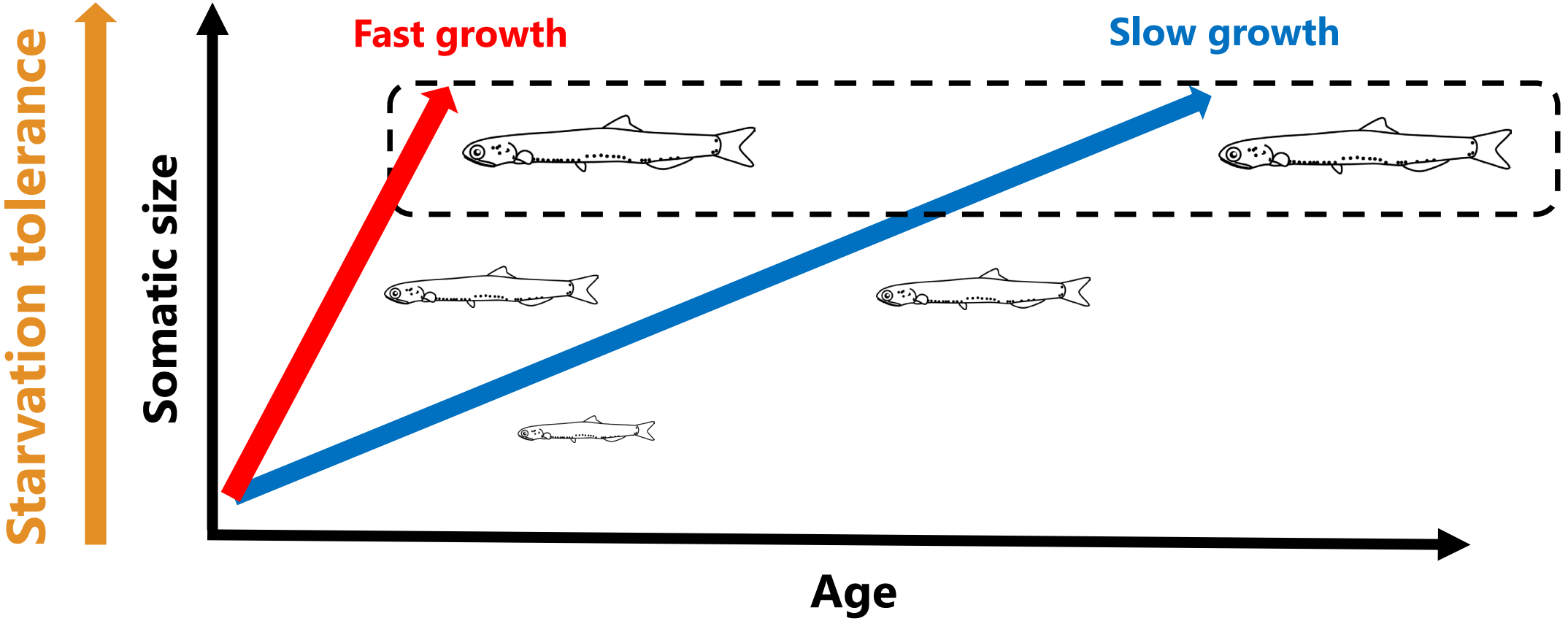

- Larger larvae may have more stored energy available to survive during starvation.

- The model containing only somatic size had the lowest AIC.

**Larval starvation tolerance is mainly explained by somatic size.**

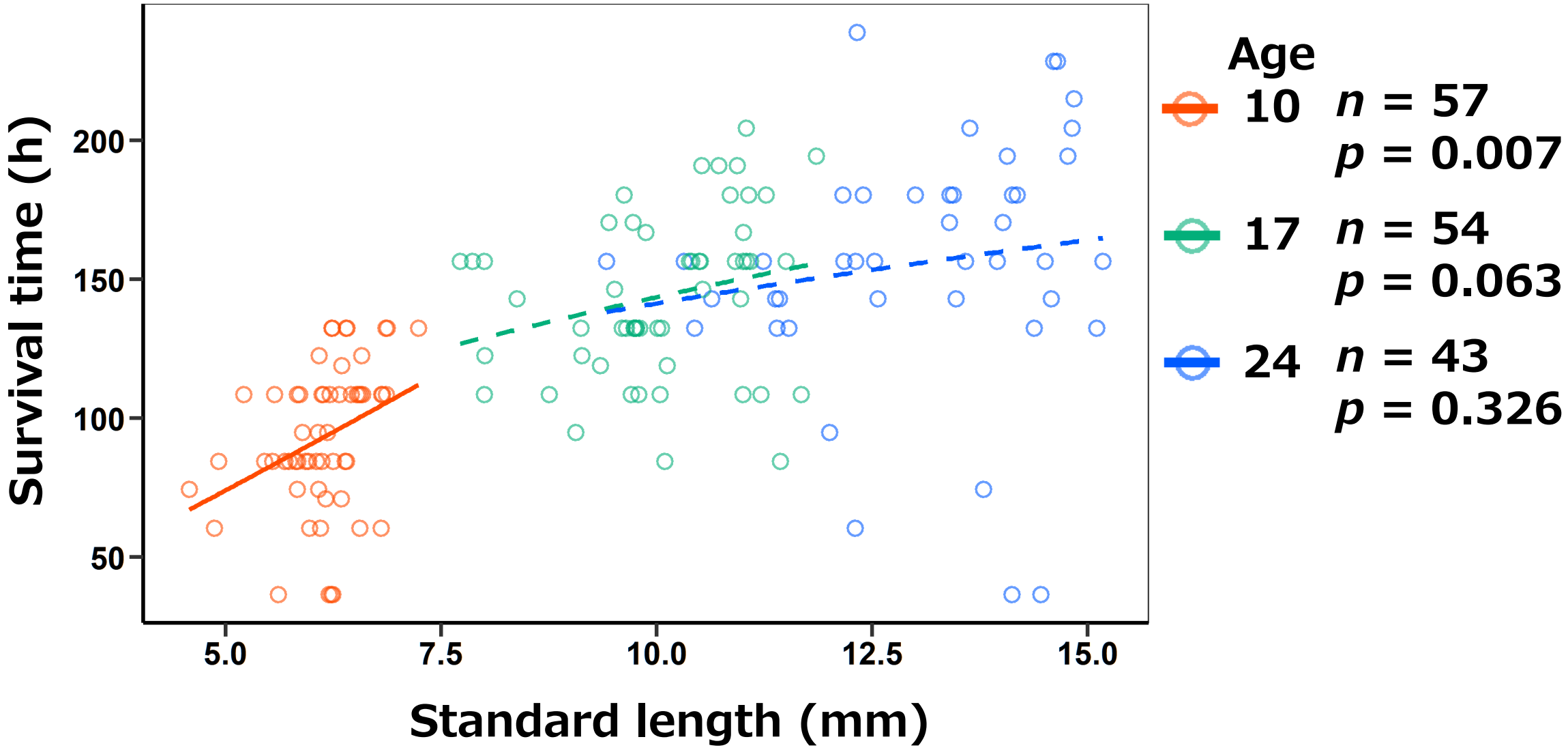
# Conclusion

**Starvation tolerance is somatic size-dependent.**

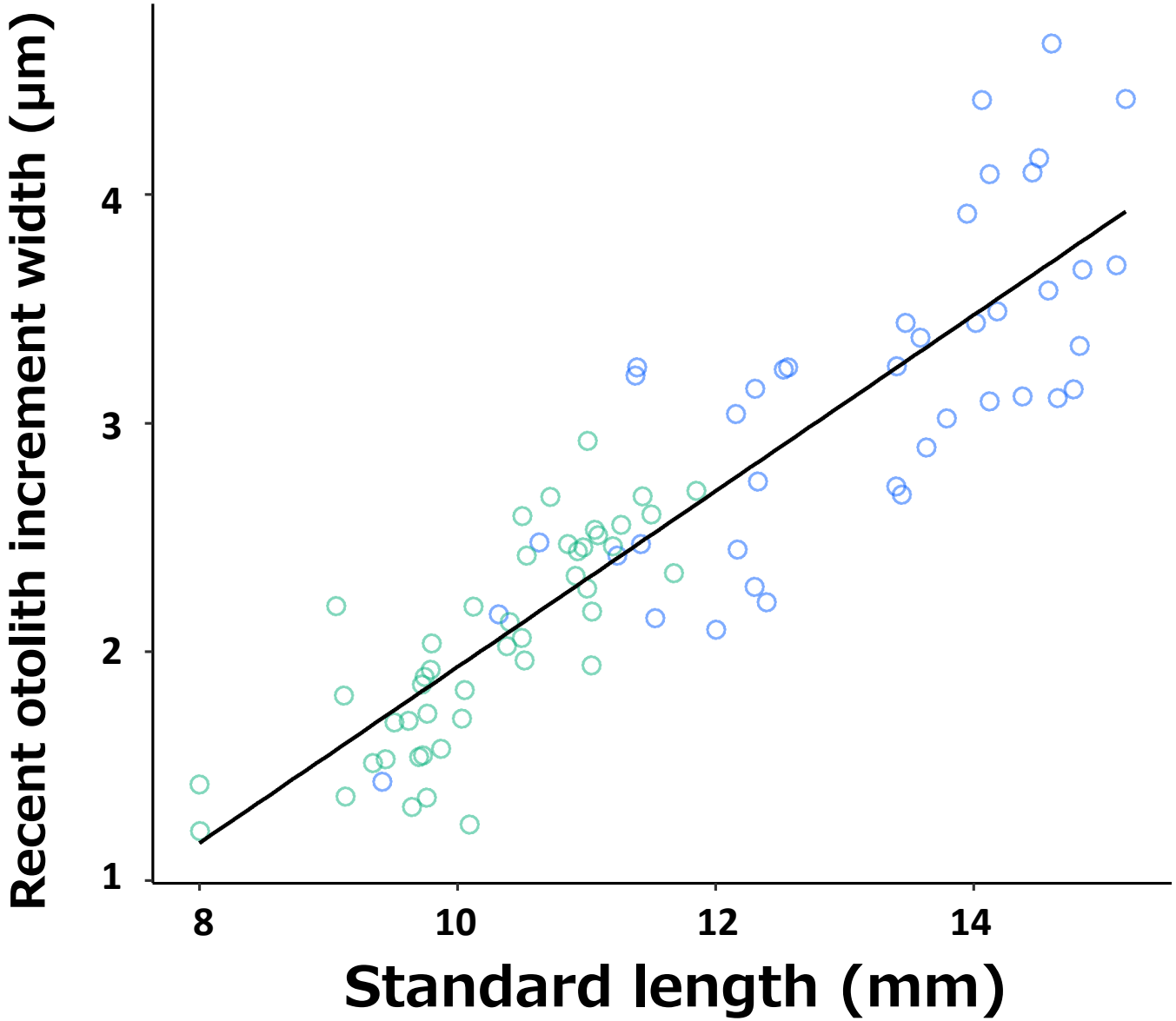



**Age and growth rate indirectly effect starvation tolerance through somatic size.**

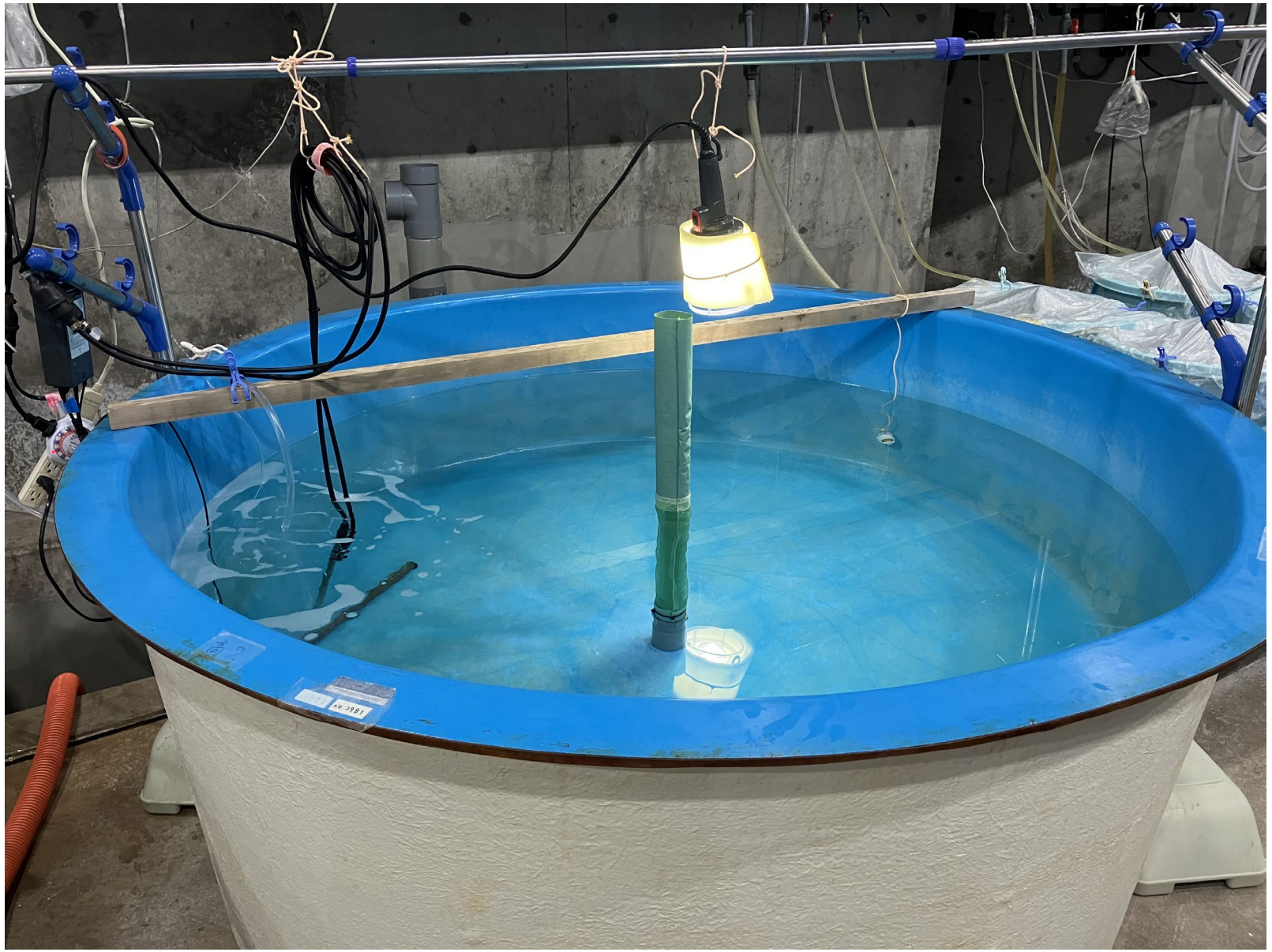
# Appendix


Survival time (h)
200
150
100
50
5.0
7.5
10.0
12.5
15.0
Standard length (mm)
Age
10 n = 57
p = 0.007
17 n = 54
p = 0.063
24 n = 43
p = 0.326

# Appendix


Recent otolith increment width (μm)
1
2
3
4
8
10
12
14
Standard length (mm)
Age (day)
17
24
R = 0.889
p < 0.001
n = 87

# Appendix



# Appendix

