# Variability in seasonal cycles of zooplankton in the seas surrounding Korean peninsula

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# Contents

# Background & hypotheses

- **Background**
  - Three Seas with different physical characteristics
  - Respond to regime shifts

- **Hypotheses**
  - Seasonal cycles will respond differently to spatial scale with different physical characteristics
  - Seasonal cycles will respond differently to regime shifts

# Data and Method

- **Zooplankton collection**
  - Hauling vertically with NORPAC net (0.33mm mesh size and 0.5m mouth diameter) from bottom or 100m depth to surface
  - 6 times in a year (February, April, June, August, October and December)
- **Zooplankton biomass**
  - Express as the wet weight of zooplankton, smaller than 3 cm in body size per cubic meter

## Data

- Zooplankton biomass : 1965~2000
- Abundance of four zooplankton groups : 1978-2000 (Copepoda, Amphipoda, Chaetognatha and Euphausiid)

## Statistics

- Duncan's multiple comparison test (Based on one-way ANOVA –test; SPSS Version 10.0)
- Self-Organizing Mapping (SOM; Kohonen, 2001)

# Map & sampling stations

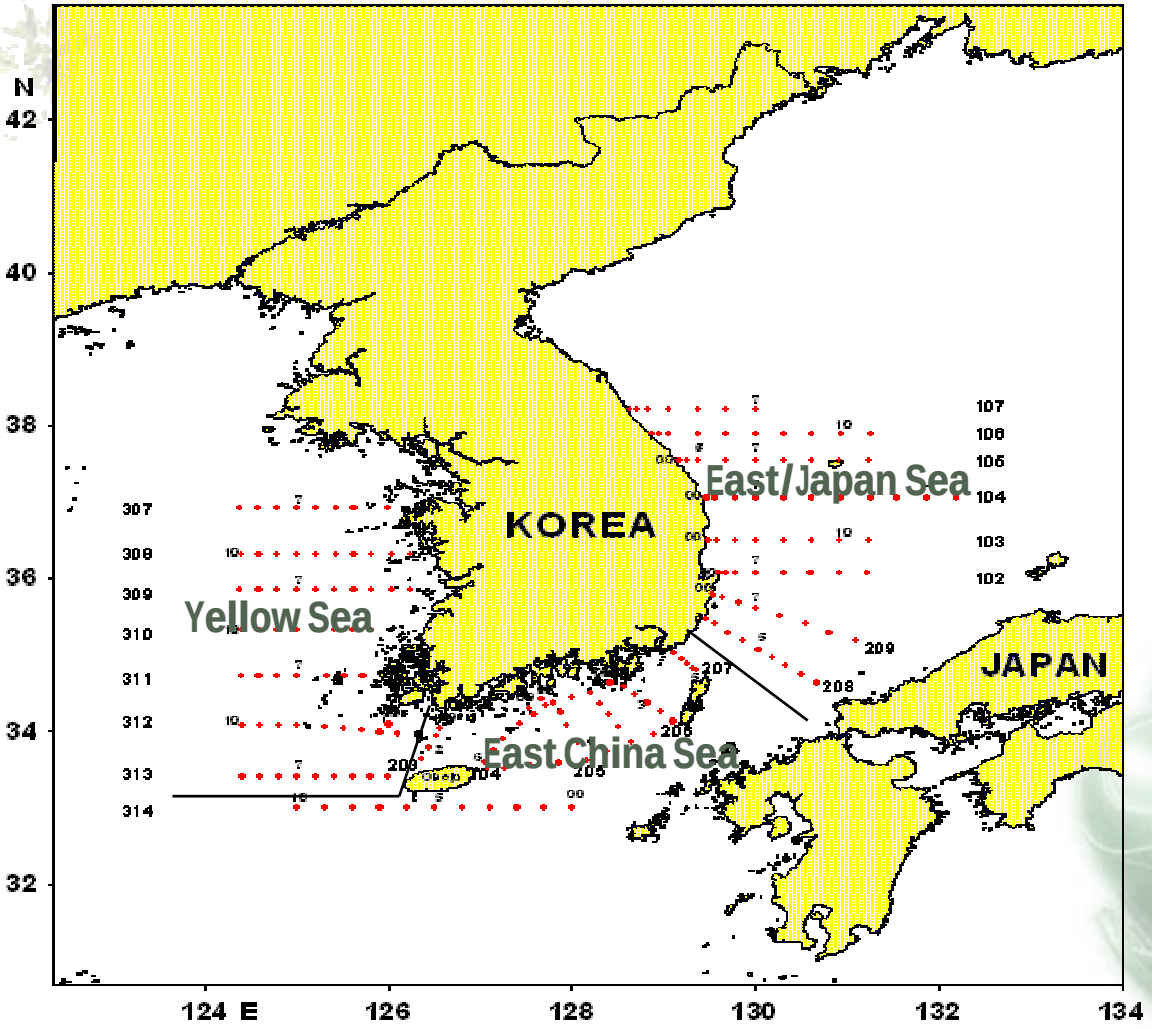



Fig. 1. Map showing the survey area.

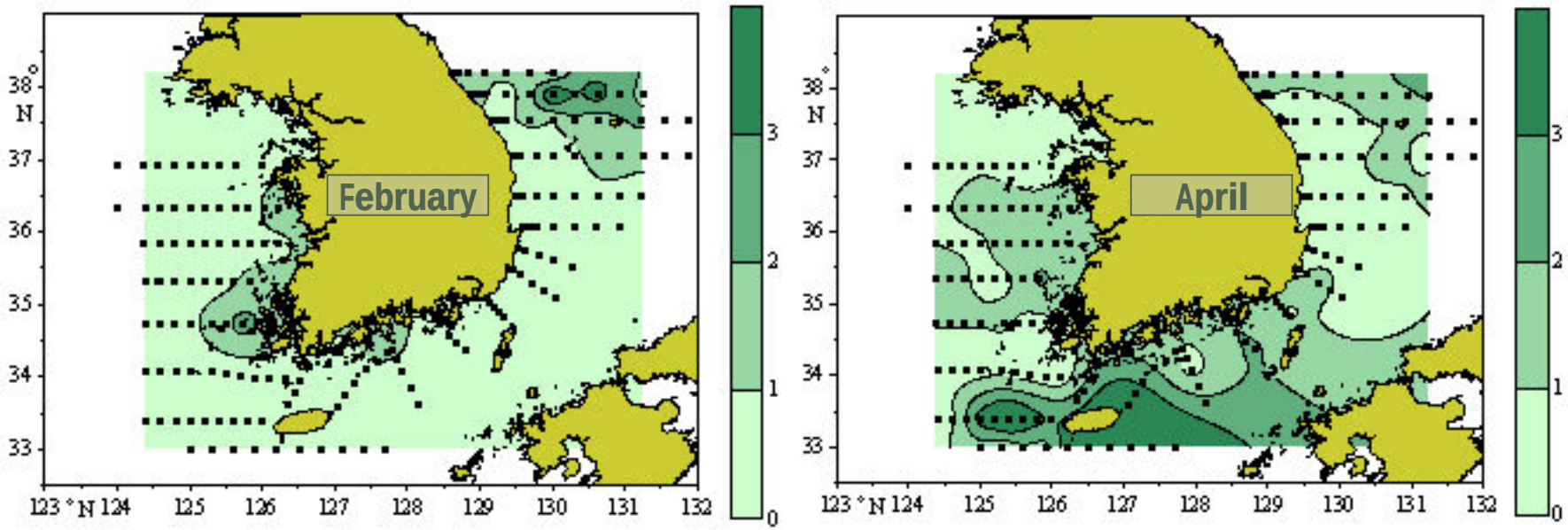
# Characteristics of three seas

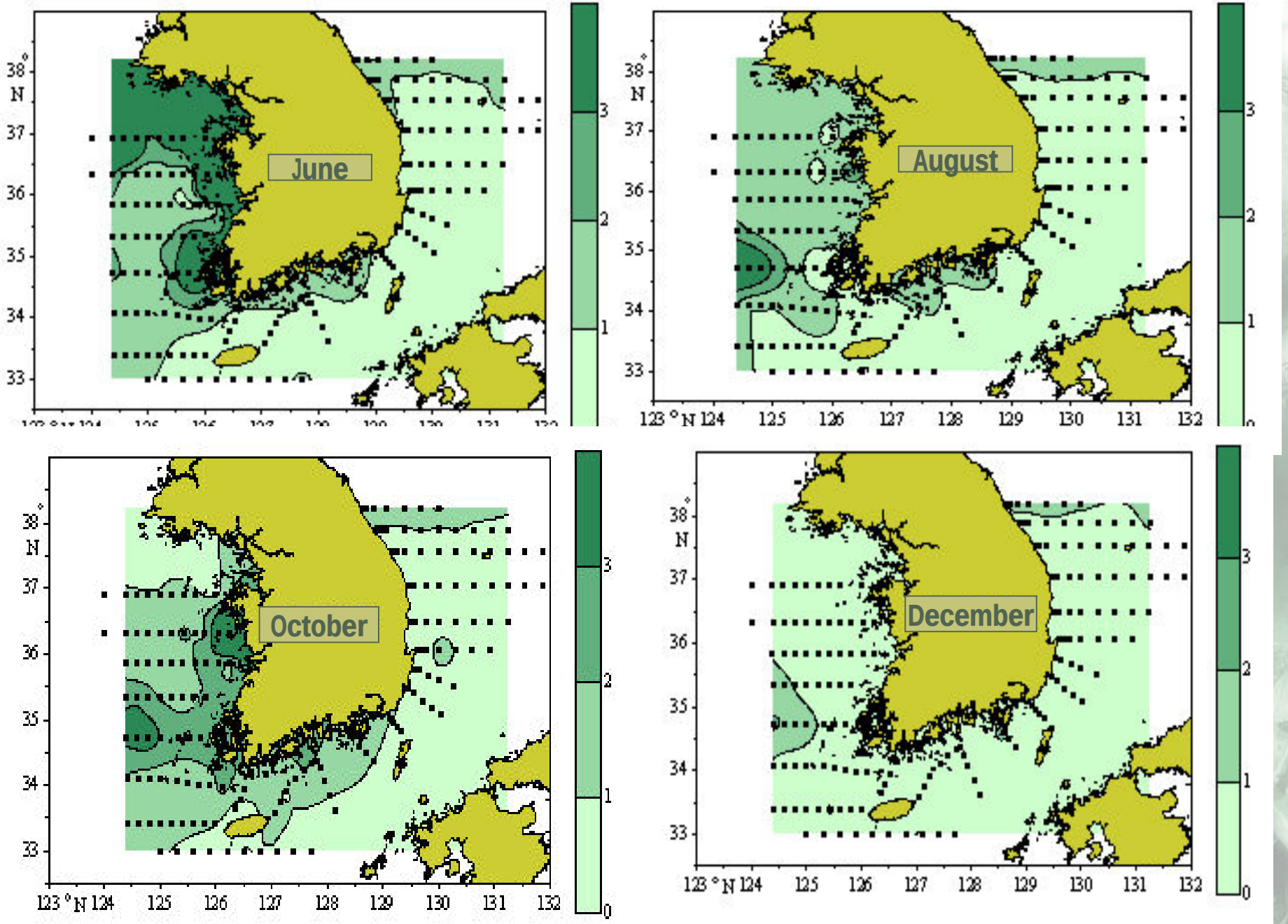
- **East / Japan Sea :**
  - Deep
  - East Korea Warm Current ( Branch of Tsushima Warm Current )
  - North Korea Cold Current
  - Polar Front
  - Coastal upwelling

- **Yellow Sea :**
  - Shallow (Mean depth=44m)
  - Yellow Sea Warm Current intrudes from East China Sea episodically in winter
  - Large tidal ranges, strong tidal fronts and tidal currents

- **Northern East China Sea :**
  - Shallow (less than 100m depth)
  - Tsushima Warm Current
  - Low-salinity Yangtze River water
  - Coastal fronts
  - Strong water exchange with East / Japan Sea
  - Weak water exchange with Yellow Sea

# Seasonal variation in geographical distributions




June
August
October
December
38° N
37
36
35
34
33
123 °N 124
125
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127
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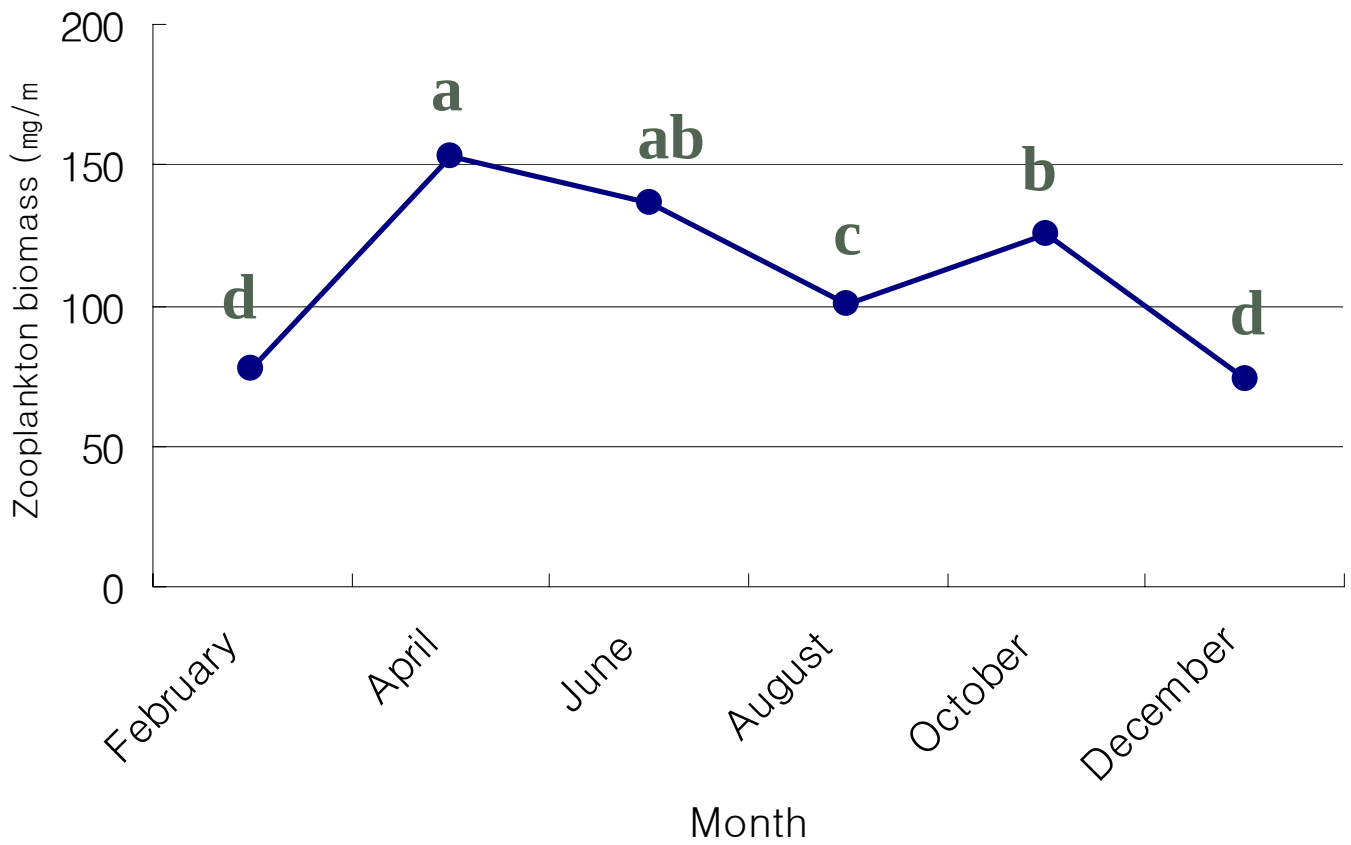
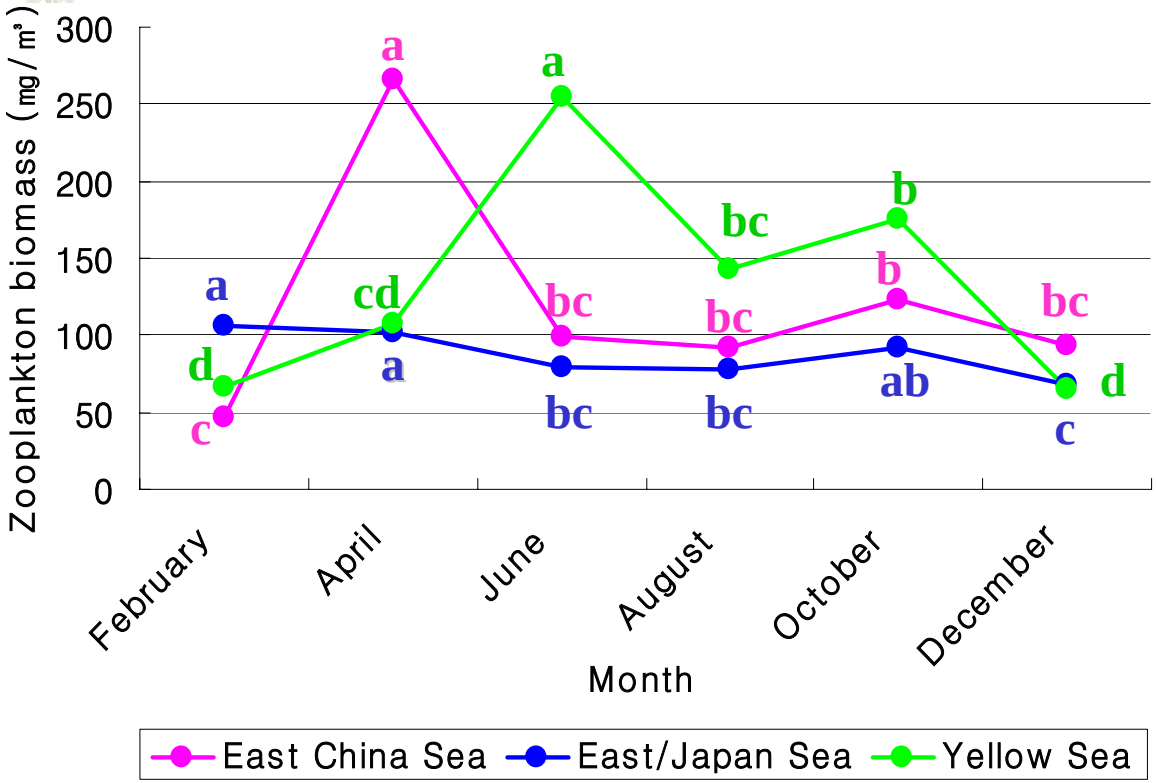
0
1
2
3

# Seasonal variations in zooplankton biomass in three seas combined (Korean waters)




•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal variations in zooplankton biomass in each sea




•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# ❖ Synopsis : Seasonal peaks of zooplankton biomass

| Sea | East/Japan Sea | Northern East China Sea | Yellow Sea |
|---|---|---|---|
| Month | February, April (October) | April (October) | June (October) |

# Seasonal variations in abundance of zooplankton groups in three seas combined (Korean waters)

| | February | April | June | August | October | December |
|---|---|---|---|---|---|---|
| Copepoda | D (n=1,640; 76±112) | B (n=1,732; 174±359) | A (n=1,742; 325±1,403) | CD (n=1,751; 104±176) | D (n=1,758; 128±185) | CD (n=1,542; 95±157) |
| Amphipoda | C (n=1,647; 1.3±4.4) | C (n=1,738; 1.6±6.9) | A (n=1,750; 6.2±50.3) | BC (n=1,755; 3.2±10.8) | AB (n=1,759; 5.1±80.6) | BC (n=1,549; 3.4±8.7) |
| Chaetognatha | C (n=1,647; 32.3±148.9) | D (n=1,738; 14.4±62.9) | D (n=1,751; 14.0±83.8) | A (n=1,755; 70.8±380.1) | B (n=1,758; 128±185) | CD (n=1,542; 95±157) |
| Euphausiid | B (n=1,646; 3.5±37.2) | A (n=1,738; 10.7±154.5) | A (n=1,751; 16.3±191.6) | B (n=1,755; 2.5±16.4) | B (n=1,760; 2.3±16.4) | B (n=1,549; 3.1±6.5) |

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal variations in abundance of zooplankton groups in the East/Japan Sea

| | February | April | June | August | October | December |
|---|---|---|---|---|---|---|
| Copepoda | C (n=683; 66±112) | A (n=724; 141±311) | B (n=728; 111±410) | C (n=754; 72±98) | C (n=727; 70±77) | C (n=691; 70±90) |
| Amphipoda | C (n=683; 2.0±4.2) | C (n=724; 2.3±8.4) | A (n=728; 5.5±17.7) | B (n=754; 3.4±8.2) | B (n=727; 4.0±8.4) | B (n=691; 3.8±8.2) |
| Chaetognatha | C (n=683; 1.5±4.3) | C (n=724; 1.3±2.6) | B (n=728; 2.5±4.7) | A (n=754; 4.0±7.1) | A (n=727; 4.4±11.4) | B (n=691; 3.1±8.8) |
| Euphausiid | C (n=683; 0.7±1.5) | A (n=724; 1.9±3.8) | B (n=728; 1.5±4.2) | AB (n=754; 1.8±4.8) | AB (n=727; 1.8±4.9) | C (n=691; 0.9±3.8) |

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal variations in abundance of zooplankton groups in the Northern East China Sea

| | February | April | June | August | October | December |
|---|---|---|---|---|---|---|
| Copepoda | C (n=465; 89±124) | A (n=513; 197±290) | B (n=496; 121±164) | C (n=480; 87±89) | A (n=516; 179±211) | A (n=439; 175±248) |
| Amphipoda | D (n=471; 0.5±1.5) | C (n=519; 1.9±7.5) | B (n=505; 3.3±7.1) | B (n=484; 3.1±7.1) | A (n=518; 4.7±9.2) | A (n=446; 4.7±9.2) |
| Chaetognatha | E (n=472; 1.2±2.4) | E (n=519; 1.6±4.5) | D (n=505; 3.0±5.9) | B (n=484; 6.2±10.2) | A (n=518; 8.3±14.0) | C (n=446; 4.7±8.8) |
| Euphausiid | D (n=472; 0.5±1.8) | A (n=519; 5.2±14.8) | B (n=505; 3.2±7.9) | BC (n=484; 2.7±11.5) | BC (n=518; 2.6±5.9) | C (n=446; 1.7±4.1) |

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal variations in abundance of zooplankton groups in the Yellow Sea

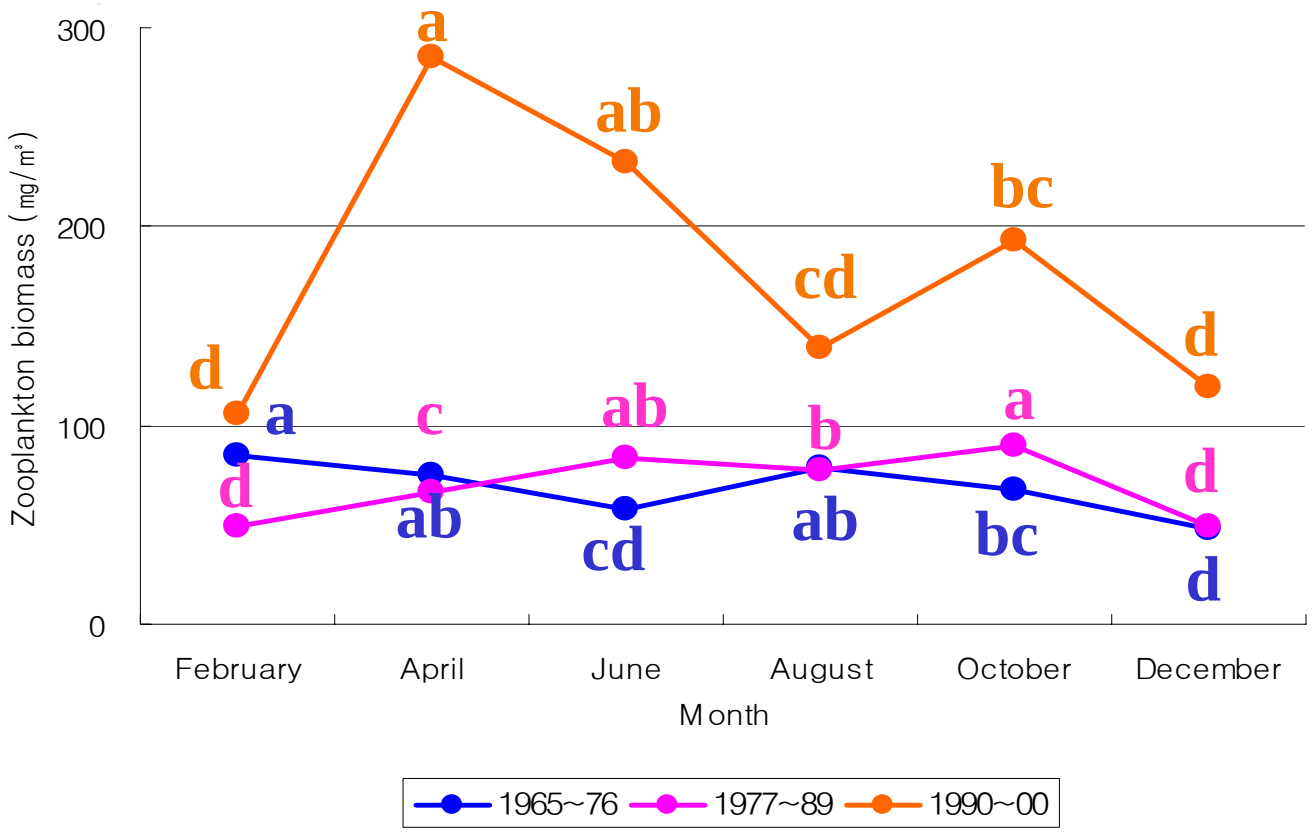
| | February | April | June | August | October | December |
|---|---|---|---|---|---|---|
| Copepoda | C (n=542; 73±94) | B (n=545; 146±178) | A (n=568; 399±576) | B (n=567; 140±249) | B (n=565; 160±243) | C (n=462; 63±79) |
| Amphipoda | A (n=542; 0.8±5.6) | A (n=545; 0.1±0.6) | A (n=568; 1.0±7.4) | A (n=567; 3.1±15.2) | A (n=565; 7.3±141) | A (n=462; 1.6±8.4) |
| Chaetognatha | C (n=542; 94.6±248.3) | D (n=545; 42.4±107.0) | D (n=568; 32.9±137.4) | A (n=567; 205.3±648.3) | B (n=565; 144.0±376.2) | CD (n=461; 73.1±223.9) |
| Euphausiid | B (n=542; 9.2±64.5) | AB (n=545; 26.3±275.0) | A (n=568; 43.4±334.2) | B (n=567; 4.0±28.0) | B (n=565; 2.6±15.4) | B (n=462; 3.1±10.9) |

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

## ❖ Synopsis : Seasonal peaks of abundance of four zooplankton groups

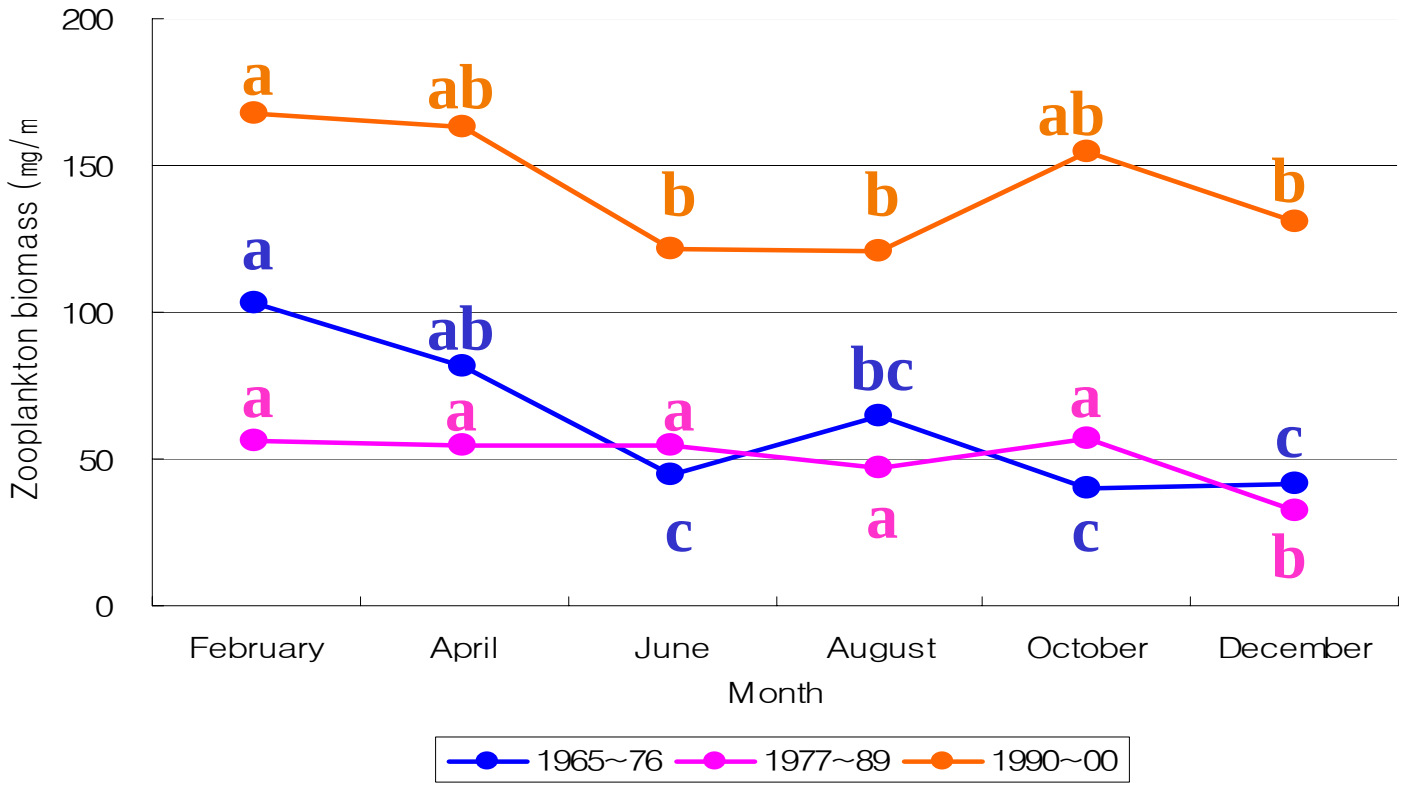
| | East/Japan Sea | Northern East China Sea | Yellow Sea |
|---|---|---|---|
| Copepoda | April | April/ October, December | June |
| Amphipoda | June | October, December | None |
| Chaetognatha | August, October | October | August |
| Euphausiid | April | April | June |

# Seasonal cycles in zooplankton biomass in three seas combined (Korean waters) in response to regime shifts



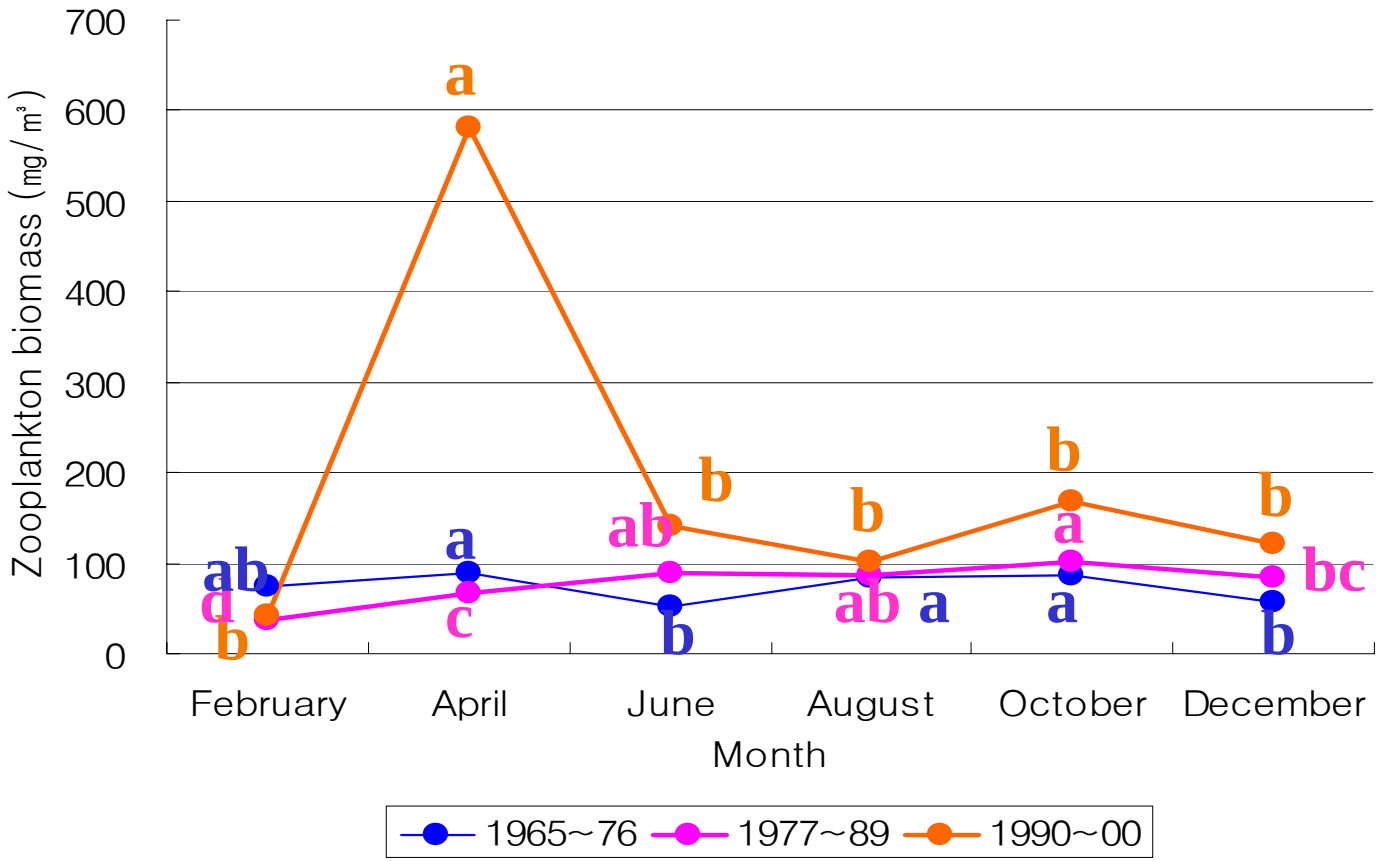

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal cycles in zooplankton biomass in the East/Japan Sea in response to regime shifts



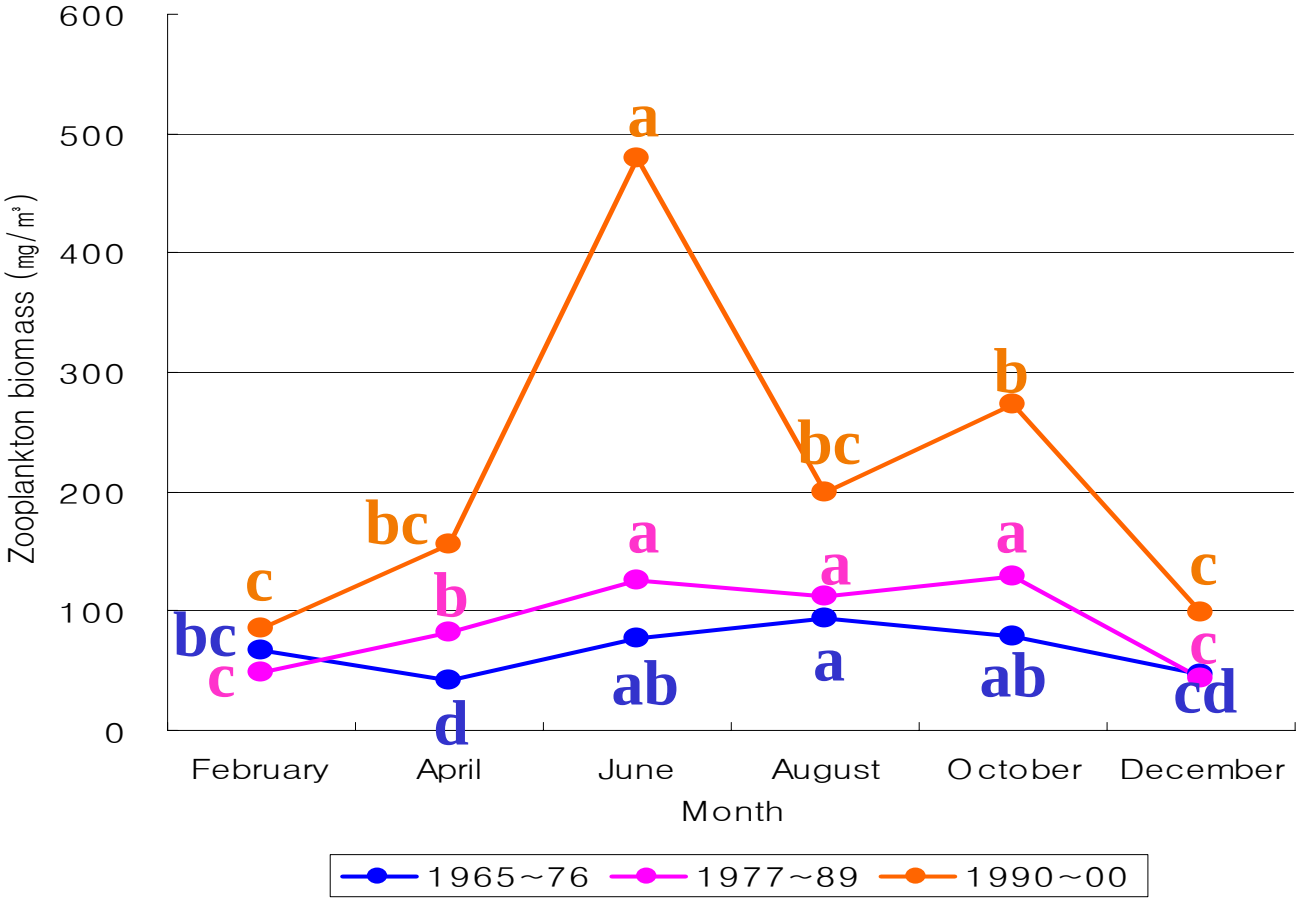

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal cycles in zooplankton biomass in the Northern East China Sea in response to regime shifts




•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

# Seasonal cycles in zooplankton biomass in the Yellow Sea in response to regime shifts

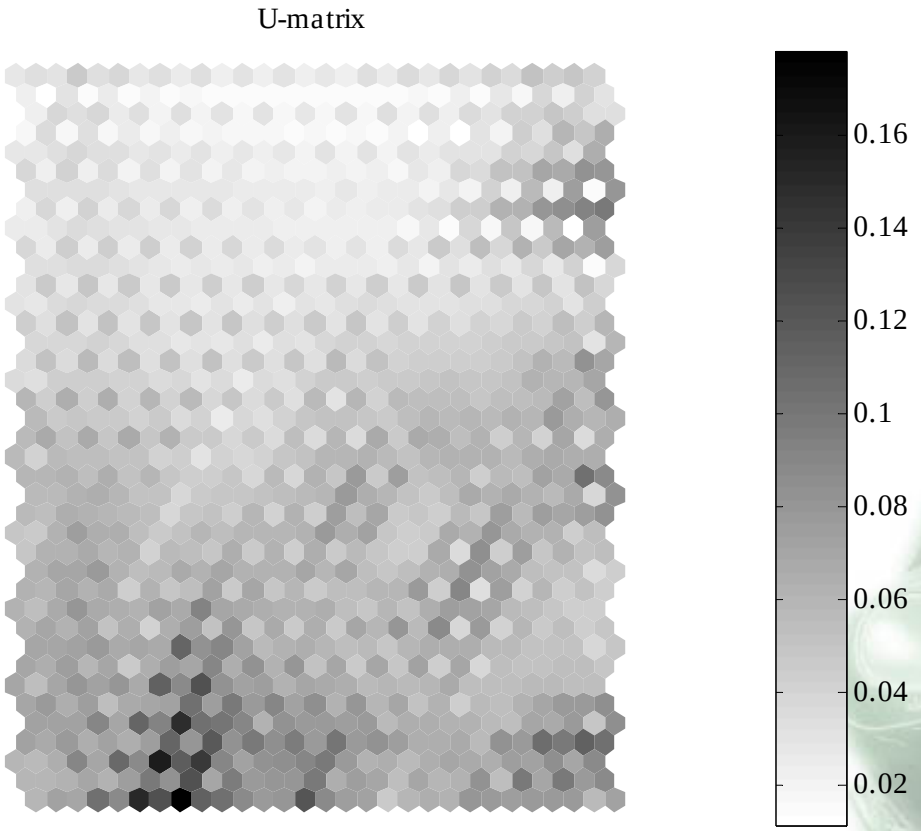


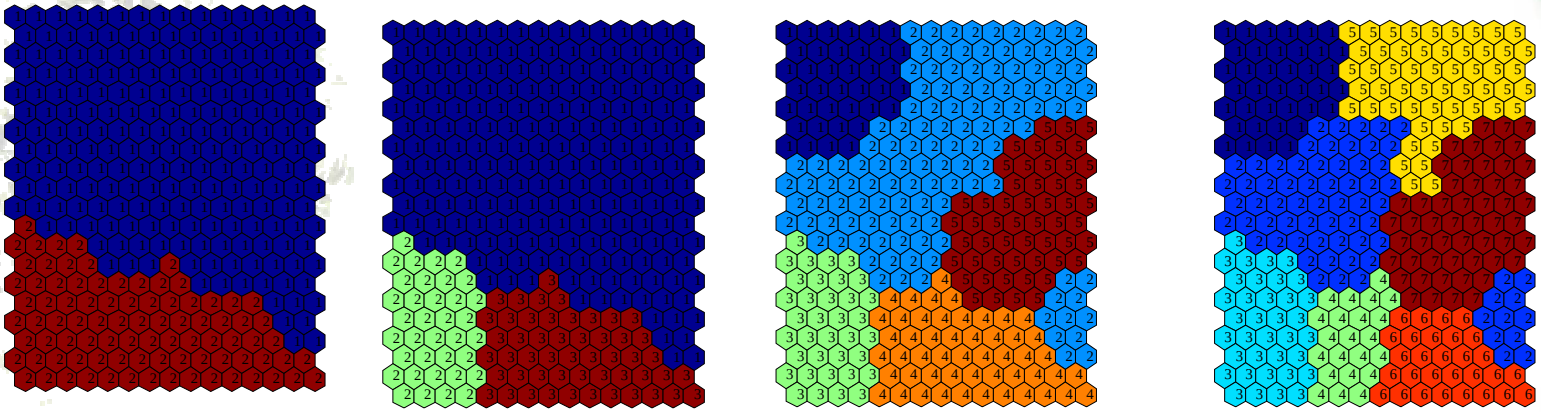

•Different letters indicate significantly different mean (Duncan's multiple comparison test; $p<0.05$).

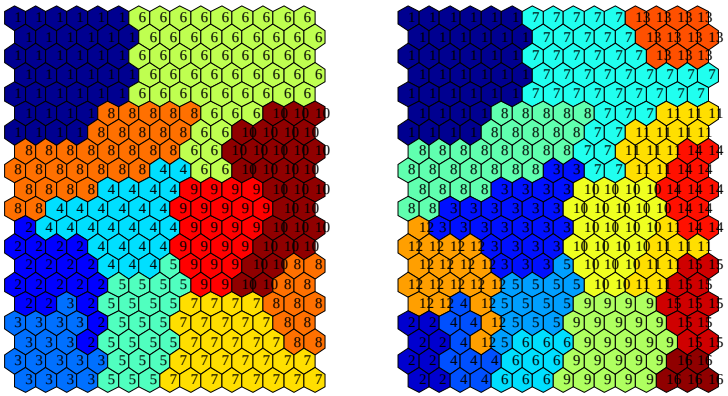
# Synopsis : Seasonal peaks of zooplankton biomass in response to regime shifts

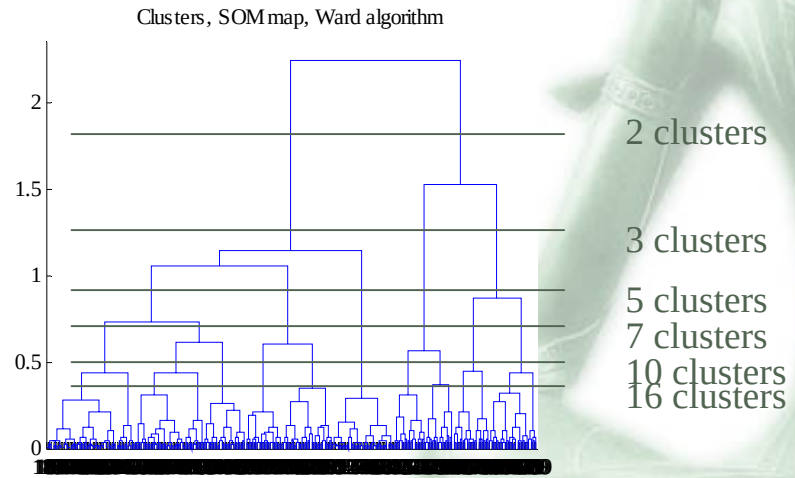
| | East/Japan Sea | Northern East China Sea | Yellow Sea |
|---|---|---|---|
| 1965~76 | February (weak) | April/ August, October (very weak) | August (weak) |
| 1977~89 | February ~October (no peak) | October (weak) | August ~October (weak) |
| 1990~00 | February (weak) | April (strong) | June (strong) |

# Self-Organizing Mapping (U-matrix) with four zooplankton groups

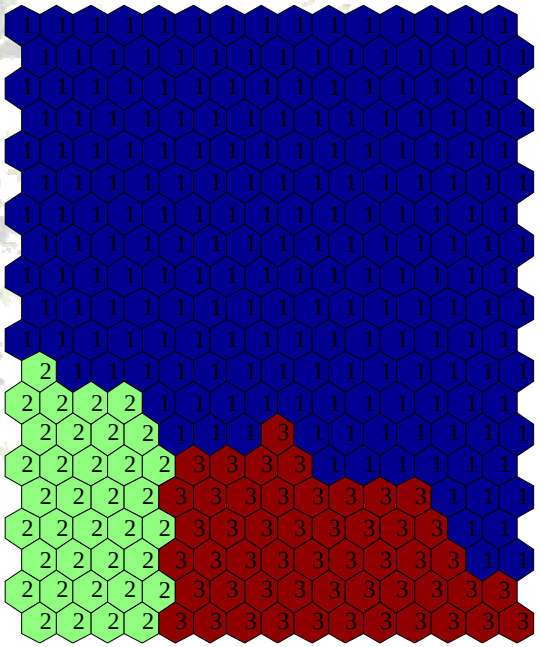




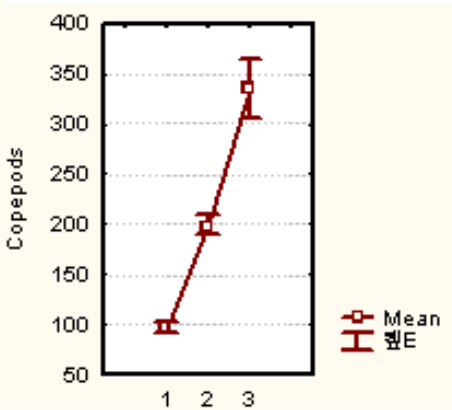




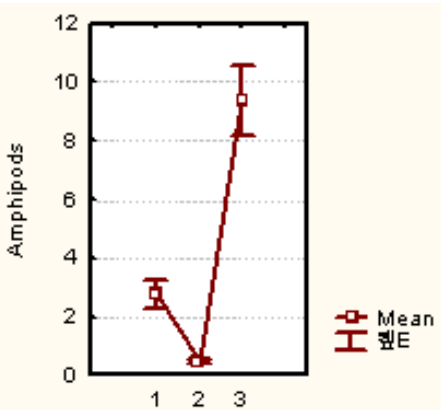

# Classification of clusters by the SOM map



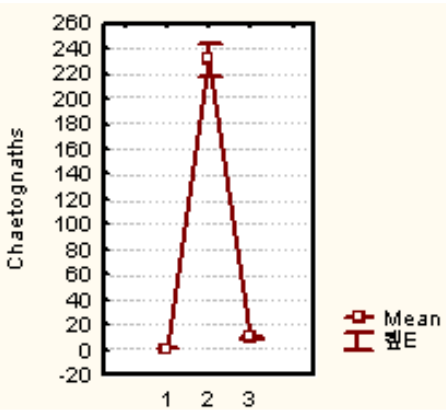
| | Cluster I | Cluster II | Cluster III | |
|---|---|---|---|---|
| Copepoda | Low | Middle | High | |
| Amphipoda | Middle | Low | High | |
| Chaetognatha | Low | High | Low | |
| Euphausiid | Low | Low | High | |



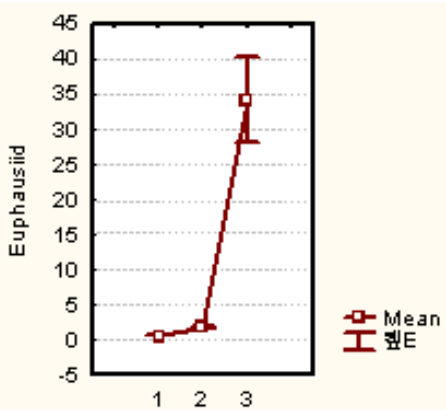

Cluster




Cluster




Cluster




Cluster

# Frequency of sites for Cluster I

| | Month | 1st period (1978~89) | 2nd period (1990~00) |
|---|---|---|---|
| East/Japan Sea | February | 339 (97.7 %) | 237(85.3%) |
| | April | 348 (98.0% ) | 195(67.2%) |
| | June | 314(89.7%) | 225(78.7%) |
| | August | 318 (86.9%) | 188(63.5%) |
| | October | 349 (93.1%) | 149(55.0%) |
| | December | 366 (97.3%) | 203(70.0%) |
| Northern East China Sea | February | 231 (97.5%) | 125(82.2%) |
| | April | 223 (92.5%) | 93(51.1%) |
| | June | 214 (88.8%) | 102(62.6%) |
| | August | 204 (91.1%) | 99(57.6%) |
| | October | 198 (85.3%) | 84(42.9%) |
| | December | 204 (93.6%) | 122(72.2%) |
| Yellow Sea | February | 156 (60.2%) | 88(34.4%) |
| | April | 132 (47.1%) | 90(30.8%) |
| | June | 149 (49.5%) | 81(28.6%) |
| | August | 164 (55.4%) | 70(24.3%) |
| | October | 138 (45.8%) | 56(18.3%) |
| | December | 163 (57.8%) | 73(36.1%) |

* % indicates sampling site frequency in each cluster over total sampling sites.

# Frequency of sites for Cluster II

| | Month | 1st period (1978~89) | 2nd period (1990~00) |
|---|---|---|---|
| East/Japan Sea | February | 3 (0.9%) | 2(0.7%) |
| | April | 0(0%) | 1(0.3%) |
| | June | 2(0.6%) | 2(0.7%) |
| | August | 8(2.2%) | 12(4.1%) |
| | October | 8(2.1%) | 8(3.0%) |
| | December | 1(0.3%) | 6(2.1%) |
| Northern East China Sea | February | 2(0.8%) | 2(1.3%) |
| | April | 0(0%) | 1(0.5%) |
| | June | 1(0.4%) | 4(2.5%) |
| | August | 2(0.9%) | 21(12.2%) |
| | October | 12(5.2%) | 16(8.2%) |
| | December | 8(3.7%) | 2(1.2%) |
| Yellow Sea | February | 81(31.3%) | 137(53.5%) |
| | April | 94(33.6%) | 99(33.9%) |
| | June | 64(21.3%) | 71(25.1%) |
| | August | 96(32.4%) | 176(61.1%) |
| | October | 109(36.2%) | 203(66.3%) |
| | December | 86(30.5%) | 88(43.6%) |

* % indicates sampling site frequency in each cluster over total sampling sites.

# Frequency of sites for Cluster III

| | Month | 1st period (1978~89) | 2nd period (1990~00) |
|---|---|---|---|
| East/Japan Sea | February | 5(1.4%) | 39(14.0%) |
| | April | 7(2.0%) | 94(32.4%) |
| | June | 34(9.7%) | 59(20.6%) |
| | August | 40(10.9%) | 96(32.4%) |
| | October | 18(4.8%) | 114(42.1%) |
| | December | 9(2.4%) | 81(27.9%) |
| Northern East China Sea | February | 4(1.7%) | 25(16.4%) |
| | April | 18(7.5%) | 88(48.4%) |
| | June | 26(10.8%) | 57(35.0%) |
| | August | 18(8.0%) | 52(30.2%) |
| | October | 22(9.5%) | 96(49.0%) |
| | December | 6(2.8%) | 45(26.6%) |
| Yellow Sea | February | 22(8.5%) | 31(12.1%) |
| | April | 54(19.3%) | 103(35.3%) |
| | June | 88(29.2%) | 131(46.3%) |
| | August | 36(12.2%) | 42(14.6%) |
| | October | 54(17.9%) | 47(15.4%) |
| | December | 33(11.7%) | 41(20.3%) |

* % indicates sampling site frequency in each cluster over total sampling sites.

# Conclusion

- In the Korean waters, there are two peaks in zooplankton biomass, a large peak in April and a small peak in October
  - There are differences in peak time according to seas : February in the East/Japan Sea, April in the Northern East China Sea and June in the Yellow Sea.
- After 1989 regime shift, seasonal cycles was more clear, and seasonal peak appeared early.