Frontier of jellyfish blooms study: Mechanism, forecast and countermeasure of the blooms

Shin-ichi Uye (Hiroshima University)
East Asian Marginal Seas (EAMS)

Area: 0.8 % of the total marine area
Fish catch: 11% of the world marine fish catch
Human population: ca. 800 million
Environmental hot spot: global warming, eutrophication, harmful algal bloom, photochemical smog, yellow dust, jellyfish bloom
Recent jellyfish blooms in EAMS

Bloom of *Aurelia aurita* in coastal waters around EAMS

Bloom of *Nemopilema nomurai* over entire EAMS

© Asahi Shimbun
Recent jellyfish blooms in EAMS

Bloom of *Aurelia aurita* in coastal waters around EAMS

Bloom of *Nemopilema nomurai* over entire EAMS
Bloom of *Nemopilema* in the Japan Sea

1900

1950
Bloom of *Nemopilema* in the Japan Sea
Bloom of *Nemopilema* in the Japan Sea

1900 1920 1950 1958
Bloom of *Nemopilema* in the Japan Sea

1900 1920 1950 1958 1995
Bloom of *Nemopilema* in the Japan Sea
Bloom of *Nemopilema* in the Japan Sea
Bloom of *Nemopilema* in the Japan Sea

1900 1920 1950 1958 1995 03

2002
Bloom of *Nemopilema* in the Japan Sea
Bloom of *Nemopilema* in the Japan Sea

![Image of individuals in the water catching jellyfish during low tide](image-url)
Bloom of *Nemopilema* in the Japan Sea

1900 1920 1950 1958 1995 03 06

2002 05 07
Bloom of *Nemopilema* in the Japan Sea
Life cycle of *Nemopilema nomurai*
Life cycle of *Nemopilema nomurai*

- **Podocyst**
- **Polyp**
- **Strobila**
- **Planula**
- **Medusa**
- **Ephyla**

Sexual reproduction
Life cycle of *Nemopilema nomurai*

- **Podocyst**
- **Polyp**
- **Planula**
- **Ephyla**
- **Strobila**
- **Medusa**

**Sexual reproduction**

**Asexual reproduction**
Spawning season: October-December
Healthy and intact medusae have immature gonad

Immature ovary
Induced gonadal maturation by mechanical damage to medusae
Maturation completed in 3-5 days

Mature ovary

Primary oocytes: their maturation arrest at the prophase of the first meiotic division

With extraordinary large nuclei, or germinal vesicles
Light exposure: a trigger for maturation division

Germinal vesicle

GV breaks down 70 min

A pit opens 80 min

Polar body 90 min
Fecundity of a female (56 kg wet weight)

Extended length: 200 m

Estimated fecundity: ca. 0.3 billion eggs

Fecundity of a 200-kg female: > 1 billion eggs
Life cycle of *Nemopilema nomurai*

Fertilized egg
Life cycle of *Nemopilema nomurai*

**Fertilized egg**

**Planula**
Life cycle of *Nemopilema nomurai*

- **Fertilized egg**
- **Planula**
- **4-tentacle polyp**
Life cycle of *Nemopilema nomurai*

- **Fertilized egg**
- **Planula**
- **16-tentacle polyp**
- **4-tentacle polyp**
Polyp asexual reproduction

Colonized polyps and podocysts

Polyp walks!
Polyp asexual reproduction

Colonized polyps and podocysts

Polyp walks!

Strobila
Polyp asexual reproduction

Colonized polyps and podocysts

Polyp walks!

Strobila

Ephyra
ca. 1 billion eggs per female
25 billion new ephyrae from a female!

c. 1 billion eggs per female
Growth of *Nemopilema nomurai*

Daily growth rate: 3% of the body weight

\[ WW = 3.09 e^{0.031t} \]

\( r = 0.97 \)
Feeding of *Nemopilema nomurai*

**Metephyra**

- Oral arm
- Scapulet

**Medusa**

- Major prey: copepods

*Artemia* nauplii

Major prey: copepods
Feeding of *Nemopilema nomurai*

- **Wet weight:** 100 kg
- **Carbon weight:** 130 g
- **Specific growth rate:** $0.03 \text{ d}^{-1}$

**Respiration rate**
- $13.1 \text{ g C d}^{-1}$

**Growth rate**
- $3.9 \text{ g C d}^{-1}$

**Assimilation rate**
- $17.0 \text{ g C d}^{-1}$

**Egestion rate**
- $4.3 \text{ g C d}^{-1}$

**Feeding rate**
- $21.3 \text{ g C d}^{-1}$

**Respiration rate-body weight relationship**

\[
\text{Oxygen consumption rate (ml O}_2/ \text{mg dw/hr)} = 0.012 (\text{ml O}_2/ \text{gww/hr}) \times \text{Wet weight (Kg)}
\]

Average $N=13$
Feeding of *Nemopilema nomurai*

Wet weight: 100 kg
Carbon weight: 130 g
Specific growth rate: 0.03 $d^{-1}$

Zooplankton biomass: 5 mg C m$^{-3}$
Feeding of *Nemopilema nomurai*

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- **Feeding rate** (21.3 g C d\(^{-1}\))
- **Clearance rate** (4260 m\(^3\) d\(^{-1}\))

**Zooplankton biomass:** 5 mg C m\(^{-3}\)
Feeding of *Nemopilema nomurai*

- Wet weight: 100 kg
- Carbon weight: 130 g
- Specific growth rate: 0.03 d\(^{-1}\)

**Respiration rate-body weight relationship**

- Respiration rate: 13.1 g C d\(^{-1}\)
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Zooplankton biomass: 5 mg C m\(^{-3}\)

= Olympic game swimming pool
Transport of *Nemopilema* to Japanese waters
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

CLSWM
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*
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Seeding/nursery ground of *Nemopilema*

Data © 2010 MIRC/JHA
Image © 2010 TerraMetrics
© 2010 Cnes/Spot Image
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

June

CLSWM

Tsushima C

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Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

Claussm

June

July

Tsushima C

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Image © 2010 TerraMetrics
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Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

- June
- CLSWM
- July
- Tsushima C

Data © 2010 MIRC/JHA
Image © 2010 TerraMetrics
© 2010 Cnes/Spot Image
Seeding/nursery ground of *Nemopilema*

Transport of *Nemopilema* to Japanese waters
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

June

CLSWM

Tsushima C

July

August
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

- **June**: CLSWM
- **July**: Tsushima C
- **August**: September
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

- June
- CLSWM
- Tsushima C

- July
- August
- September
Transport of *Nemopilema* to Japanese waters

- **Seeding/nursery ground of Nemopilema**
- **CLSWM**
- **June**
- **Tsushima Current**
- **July**
- **August**
- **September**
- **October**
Seeding/nursery ground of *Nemopilema*

Transport of *Nemopilema* to Japanese waters

- June
- CLSWM
- Tsushima C
- July
- September
- August
- October
Transport of *Nemopilema* to Japanese waters

Seeding/nursery ground of *Nemopilema*

- June
- July
- August
- September
- October
- November
Spatio-temporal distribution of *Nemopilema* in 2005

- July
- August
- September
- October
- November
- December
- January
- February

Legend:
- 1～10
- 10～100
- 100～500
- 500～1000
- 1000～

*(medusae/set net/day)*
Causes: Environmental and ecosystem changes in Chinese coastal waters
Causes: Environmental and ecosystem changes in Chinese coastal waters

Global warming

(1.7°C/25 years)

(Lin et al., 2005)

Seasonal life cycle

Strobila

Planula

Polyp

Podocyst

Medusa
Causes: Environmental and ecosystem changes in Chinese coastal waters

Global warming
(1.7°C/25 years)

(Lin et al., 2005)

Eutrophication
(In Changjiang river water)

Harmful algal bloom

Environmental and ecosystem changes in Chinese coastal waters include:

- **Global warming**
  - Temperature increase of 1.7°C over 25 years (Lin et al., 2005)

- **Eutrophication**
  - Changes in nutrient levels (Si, DIP, DIN) in water (Wang, 2006)

- **Harmful algal bloom**
  - Increased incidents of harmful algal blooms (Wang, 2006)

The diagrams illustrate the seasonal life cycle of marine organisms and the changes in environmental conditions.
Causes: Environmental and ecosystem changes in Chinese coastal waters

Global warming
(1.7°C/25 years)

(Lin et al., 2005)

Eutrophication
(Si, DIP, DIN)

(In Changjian river water)

Overfishing
(Korean fish catch in YS)

(Harmful algal bloom)

Causes: Environmental and ecosystem changes in Chinese coastal waters
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- **Global warming**
  - (1.7°C/25 years)
  - (Lin et al., 2005)

- **Eutrophication**
  - (In Changjian river water)
  - (Wang, 2006)

- **Overfishing**
  - (Korean fish catch in YS)

- **Harmful algal bloom**

- **Marine construction**
Ecosystem shift in Chinese coastal waters

Fish dominated ecosystem
Ecosystem shift in Chinese coastal waters

**Human forcing**
1. global warming
2. eutrophication
3. overfishing
4. marine construction
5. others

**Fish dominated ecosystem**
Ecosystem shift in Chinese coastal waters

**Human forcing**
1) global warming
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Fish dominated ecosystem

Jellyfish dominated ecosystem

Ecosystem shift in Chinese coastal waters

Human forcing
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Fish dominated ecosystem

Jellyfish dominated ecosystem

Jellyfish spiral
Ecosystem shift in Chinese coastal waters

Human forcing
1) global warming
2) eutrophication
3) overfishing
4) marine construction
5) others

Jellyfish dominated ecosystem

Jellyfish spiral

Fish dominated ecosystem

Favorable conditions conducive to recurrent jellyfish blooms have already prevailed in Chinese coastal waters
Intermittent bloom of *Nemopilema* (Environmental factors cannot explain)

No bloom in 2008 and 2010

Big bloom in 2009
Physiological properties of podocysts

Colonized polyps and podocysts

Podocysts

Dormant for at least 8 years

Excystment

Polyp walks!
# Induction of podocyst excystment

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<th>Temperature (°C)</th>
<th>Salinity</th>
<th>Excystment (%) for 80 days</th>
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High temp.
## Induction of podocyst excystment

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**High temp.**

**Low salinities**
## Induction of podocyst excystment

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Excystment is induced when the podocysts are exposed to some extreme environmental conditions.
Hypothetical scheme to cause *Nemopilema* to bloom or non-bloom

Non-bloom year

- Mass Excystment
- Ephyra release
- Spawning
- Asexual reproduction
- Strobilation

Bloom year

- Massive bloom
- Ephyra release
- Mass Excystment
- Strobilation
- Podocyst accumulation
- Low salinity Hypoxia

Non-bloom year:
- Spawning
- Ephyra release
- Strobilation
- Asexual reproduction
- Mass Excystment
- Podocyst accumulation

Bloom year:
- Spawning
- Ephyra release
- Mass Excystment
- Strobilation
- Podocyst accumulation
- Low salinity Hypoxia
Forecast of *Nemopilema* bloom intensity by ferry-on-deck sighting survey
Ferry survey during 6-10 June, 2009

- Green: 6 June 14:00-18:30
- Blue: 7 June 07:00-14:30
- Red: 9 June 6:00-18:30
- Yellow: 8 June 07:10-19:00
- Purple: 10 June 15:50-19:00
Ferry survey during 6-10 June, 2009

Green: 6 June 14:00-18:30
Blue: 7 June 07:00-14:30
Red: 9 June 6:00-18:30
Yellow: 8 June 07:10-19:00
Purple: 10 June 15:50-19:00
Ferry survey during 4-8 July, 2009

Orange: 4 July 06:00-18:00
Yellow: 5 July 07:00-11:00

Green: 4 July 13:30-19:30
Blue: 5 July 06:00-13:00
Red: 7 July 06:00-19:00

Purple: 8 July 09:00-19:00
Ferry survey during 4-8 July, 2009

Orange: 4 July 06:00-18:00
Yellow: 5 July 07:00-11:00
Green: 4 July 13:30-19:30
Blue: 5 July 06:00-13:00
Red: 7 July 06:00-19:00
Purple: 8 July 09:00-19:00
Ferry survey during 3-7 July 2010

Orange: 3 July 6:00-18:00
Yellow: 4 July 6:00-10:30
Green: 3 July 14:00-19:00
Blue: 4 July 6:00-14:30
Red: 6 July 6:00-18:50
Purple: 6 July 17:30-19:30
Pink: 7 July 6:00-15:00
Year-to-year difference in average medusa density in the Yellow Sea in July, in relation to bloom intensity in Japanese waters.
Year-to-year difference in average medusa density in the Yellow Sea in July, in relation to bloom intensity in Japanese waters

Massive blooms
Year-to-year difference in average medusa density in the Yellow Sea in July, in relation to bloom intensity in Japanese waters.

[Graph showing medusa density in the Yellow Sea from 2006 to 2013.]

- **Massive blooms:**
  - 2006: 1.97
  - 2007: 3.17
  - 2009: 2.29

- **No blooms:**
  - 2010: 0.02
  - 2011: 0.0006
  - 2012: 0.05
  - 2013: 0.40
  - 2014: 0.42
Year-to-year difference in average medusa density in the Yellow Sea in July, in relation to bloom intensity in Japanese waters.
Simulated transport process of *Nemopilema* in the Japan Sea

**Assumptions and conditions for the model**

1) Initial position: Three (A, B and C) zones in the Tsushima Strait
2) Start of particle release: 25 June in A (blue), 30 June in B (green), 7 July in C (red)
3) Stop of particle release: 13 July
4) Calculation period: from 25 June to 15 September
5) Vertical movement: diel vertical migration

(from Watanabe et al.)
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(from Watanabe et al.)
Simulated transportation on 1 September 2009

Actual occurrence on 2 September 2009

Tsugaru Strait

Tsugaru Strait
Simulated transportation on 1 September 2009

Actual occurrence on 2 September 2009

The simulation model can forecast the date of arrival of Nemopilema
Countermeasures in set-net fishery

Number of set-nets along *Nemopilema* affected coast

- Large-scale: 6
  - Salmon: 204
  - Small-scale: 352

- Large-scale: 154
  - Small-scale: 815

- Large-scale: 74
  - Small-scale: 320
Structure of a large-scale set-net

Leading net

Trapping nets

300-600 m in length

2-5 km to the shore
Structure of a large-scale set-net

- Fish play ground
- 1st trapping net
- 2nd trapping net (Harvest net)
- Leading net

目指場
のほり
道網
箱網
落網
Structure of a large-scale set-net

Fish play ground

1st trapping net

2nd trapping net
(Harvest net)

Leading net

運動場

のほり

箱網

落網
Structure of a large-scale set-net

Fish play ground

1st trapping net

2nd trapping net (Harvest net)

Leading net
Structure of a large-scale set-net

Fish play ground
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Leading net
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Modification of set-net to reduce the damage
Modification of set-net to reduce the damage

1) Enlargement of the mesh size of the leading net → Medusae pass through the leading net
Modification of set-net to reduce the damage

1) **Enlargement of the mesh size of the leading net** → Medusae pass through the leading net

2) **Installment of bypass nets** → Entrapped medusae are removed outside the net
Modification of set-net to reduce the damage

1) **Enlargement of the mesh size of the leading net** → Medusae pass through the leading net

2) **Installment of bypass nets** → Entrapped medusae are removed outside the net

3) **Installment of a partition net** → Entrapped medusae are separated from fish and removed outside the net
Modification of set-net to reduce the damage

1) **Enlargement of the mesh size of the leading net** → Medusae pass through the leading net

2) **Installment of bypass nets** → Entrapped medusae are removed outside the net

3) **Installment of a partition net** → Entrapped medusae are separated from fish and removed outside the net

Total investment: 5-10 million JPY (ca. 35-70 thousand Euro)
Good catch under the *Nemopilema* bloom condition
Mechanisms for the bloom of *Nemopilema*

Human-induced environmental/ecosystem changes in Chinese coastal waters are primary responsible, but some biological factors (e.g. podocyst dormancy) may also be important.
Conclusion

**Mechanisms for the bloom of *Nemopilema***
Human-induced environmental/ecosystem changes in Chinese coastal waters are primary responsible, but some biological factors (e.g. podocyst dormancy) may also be important.

**Forecast of the bloom**
Year-to-year bloom intensity can be forecasted by on-deck-ferry sighting survey in early summer. Dispersal pathways and approximate arrival date of medusae to each location can be predicted by numerical models. These forecasts enable fishermen to prepare well in advance for possible jellyfish attacks.
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Countermeasures of the bloom

Modification of set-nets is effective to alleviate the damage by entrapped medusae. Such a modification is essential to keep operating set-net fisheries under recurrent jellyfish bloom conditions.
For symbiosis of human activity and coastal marine environment, “Sato-umi”, or a coastal sea with high productivity and biodiversity with human interaction

- Understanding of material cycling
- Establishment of comprehensive material cycling
- Reproduction of tidal flats and sea grass and algae beds
- Fish resource management
- Sustainable fish culture and stock enhancement