

## Recurrent jellyfish blooms in the East Asian seas: how to adapt and manage for fisheries sustainability

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*Aurelia aurita* and *Nemopilema nomurai* are bloom-forming scyphozoans in the East Asian seas, which cover <1% of the total marine area but sustain 11% of the world fish catch. Their recurring blooms exert severe nuisance primarily in net-based fisheries. In the face of increasing jellyfish populations, the fisheries have to develop adaptive and management strategies, such as identifying causes for the blooms, forecasting outbreaks, and developing countermeasures. The causes may be multiple, but closely associated with increased anthropogenic impacts to the coastal environment and ecosystem. The forecast of year-to-year bloom intensity is possible for *N. nomurai* by monitoring juvenile medusae from ships of opportunity in Chinese waters, the seeding ground of this species, and Japanese fishermen can prepare countermeasures 1-3 months in advance of jellyfish outbursts. Bloom forecasting is, however, more challenging in *A. aurita*, since all life cycle stages coexist within a relatively small geographical area such as a bay. The basic parameters for the forecast may be 1) population size of polyps, 2) population size of ephyrae, and 3) mortality of ephyrae before recruitment to the medusa stage. As countermeasures, Japanese fishermen have introduced various types of jellyfish excluding devices in their fishing nets.

### Jellyfish blooms in the East Asian seas

The East Asian seas, which cover less than 1% of the total marine area, are highly productive fisheries grounds, producing ca. 11% of the world fish catch. This sea area, however, is designated as one of environmental hotspots being deteriorated by various human impacts (Halpern et al. 2008), because ca. 800 million humans live in the surrounding coastal land area. In this region there are two representative bloom-forming scyphozoan species, i.e. the moon jellyfish *Aurelia aurita* s.l., which tends to bloom regularly on a seasonal basis in many eutrophic bays and inlets of China, Japan and Korea, and the giant jellyfish *Nemopilema nomurai*, which blooms rather irregularly, and when it does it expands its geographical range over the East Asian Marginal Seas (i.e. the Bohai, Yellow, East China and Japan Seas). As for *A. aurita* in the Inland Sea of Japan, a semi-enclosed coastal sea in southwestern Japan, the population has increased significantly since the 1980s, most prominently in the 1990s, based on analysis of fishers' perception (Uye and Ueta 2004). The annual fish catch in the Inland Sea of Japan was highest (average: ca. 400,000 tons) during the late 1970s and early 1980s, and then has declined steadily to 173,000 tons in 2012. In the Japan Sea, the population outbreak of *N. nomurai* was very rare, once per ca. 40 years, in the last century (i.e. in 1920, 1958 and 1995), but it occurred much more frequently in this century, almost annually from 2002 to 2009. In recent 5 years (i.e. from 2010 to 2014), however, only a small number of medusae appeared. A big 2005 bloom of *N. nomurai* resulted in Japanese nationwide loss of ca. 220 million EUR (Uye 2011). Slightly lesser damage by *N. nomurai* outbreak was reported in Korean fisheries in 2006, 2007 and 2009 (ca. 50-150 million EUR, Kim et al. 2012). The total fish catch in the East Asian seas is markedly declining; Japanese statistics show that annual landings from the East China Sea was stable (average: ca. 1,700,000 tons) during the 1970s and 1980s, and thereafter has decreased to a historical low level (465,000 tons) in 2009. In the face of increasing jellyfish populations, the fisheries have to develop adaptive and management strategies, such as identifying causes for the jellyfish blooms, forecasting their outbreaks, and developing countermeasures to alleviate their damage.

### Causes for jellyfish blooms

Causes for the blooms of *A. aurita* and *N. nomurai* in East Asian seas may be attributed to regional environmental and ecosystem changes rather than to decadal climate changes or regime shifts. However, it is difficult to specify which factors are actually responsible for the increase of each jellyfish population, since multiple factors, such as overfishing, global warming, eutrophication, change in nutrient composition, hypoxia, loss of biodiversity, marine infrastructure, coastal garbage, etc. are considered to be drivers. Since these factors stem from our human activities under current economic development, it is very challenging to stop degradation of marine ecosystems.

### Forecast of jellyfish outbreaks

Owing to extensive horizontal transportation (or expatriated migration) of *N. nomurai* medusae from Chinese coastal waters, the seeding and nursery ground, to Japanese waters, primarily by the Tsushima Current, year-to-year bloom intensity can be forecasted by monitoring of young medusae in Chinese waters from ships of opportunity (Uye 2014). In July of 2009, a year of the biggest bloom in this century, the Fisheries Agency of Japan announced a jellyfish warning based on unusually high medusa density in the Yellow and East China Seas revealed by this monitoring. Thus, fishermen could prepare countermeasures well in advance, so that the nationwide loss was reduced to ca. 1/3 of that of 2005. The timing of appearance of medusae into various Japanese regions can also be predicted by a hydrodynamic modeling. Bloom forecasting is, however, more challenging in *A. aurita*, since all life cycle stages coexist within a relatively small geographical area. In order to forecast likely outbreaks prior to the season of medusa bloom, it is necessary to determine the following biological parameters: 1) habitats and population size of benthic polyps, 2) population size of ephyrae, and 3) mortality of ephyrae before recruitment to the medusa stage.

### Development of countermeasures

In the face of increased *A. aurita* populations and associated nuisance in larval anchovy fisheries by two-boat trawl nets in the Inland Sea of Japan, fishermen introduced modified nets with jellyfish excluding devices in the 1980s, and now nearly 100% fishermen use these modified nets. With recurrent blooms of *N. nomurai* from the turn of this century, towed fishing nets with a device to separate jellyfish from target species (finfishes and crabs) have been invented and deployed (Matsushita and Honda 2006). Modifications have also been made in traditional set nets, to which the damage by medusae is always greatest, by enlargement of the mesh size of the leading nets, and installation of bypass nets and a partition net. Such modified set nets functioned effectively to remove entrapped medusae and yielded regular fish catches even during the months of heaviest jellyfish aggregation (October-December) in 2009 (Uye 2014). When the jellyfish outburst is so intense as to overwhelm excluders and cause serious damage to nets, it may be necessary to stop their operation and implement a fishing moratorium.

### References

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