

## Research Advances in Acoustic Observation and Assessment Techniques for Large Jellyfish: Post-print

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### Abstract

Since the late 20th century, large jellyfish blooms have frequently occurred in various oceanic regions worldwide, causing tremendous damage to marine ecosystems, fisheries, coastal industries, and tourism. To investigate the ecological habits of large jellyfish, elucidate their bloom mechanisms, and enable disaster early warning and prevention, scholars both domestically and internationally have conducted extensive monitoring and surveys employing diverse methods including nets, visual observation, underwater cameras, acoustic technology, and aerial imagery. Among these approaches, the application of acoustic technology for resource assessment and behavioral tracking of large jellyfish has been implemented in developed fishing nations such as European and American countries, Japan, and South Korea, demonstrating promising observational efficacy and application potential in studies of resource evaluation and kinematic patterns. Currently, few published studies exist in China regarding the application of acoustic observation techniques for large jellyfish research. This paper introduces international research achievements in utilizing acoustic technology for resource surveys and assessment, spatial distribution monitoring, and movement pattern analysis of large jellyfish, thereby providing a theoretical foundation and scientific basis for future acoustic research on large jellyfish in China. Based on this analysis, we recommend drawing upon international research experiences employing scientific echosounders, high-resolution imaging sonar, acoustic tags, and other methods for monitoring, surveying, and resource assessment of large jellyfish. Combined with actual conditions, acoustic technology should be progressively researched and applied to resource surveys and assessment, natural ecological habit studies, and dynamic monitoring and early warning systems for large jellyfish in key waters of China, thereby improving the nation's large jellyfish monitoring and survey system.

## Full Text

### Review of Acoustic Techniques in the Monitoring and Assessment of Giant Jellyfish

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**Abstract:** Since the end of the 20th century, giant jellyfish blooms have occurred on a nearly annual basis around the globe and have had disastrous effects on the ecology of marine systems, fishery resources, coastal industries, and coastal tourism. Researchers, both domestically and abroad, have thoroughly investigated this phenomenon using nets, visual observations, underwater cameras, acoustic technology, and aerial imagery, among other techniques to elucidate the underlying mechanisms of these blooms. In recent years, acoustic technology has been used to investigate cultured giant jellyfish stock and their behavior in fisheries in Europe, the United States, Japan, and Korea. These technologies have demonstrated favorable monitoring capabilities and the potential for their application in both resource assessment and the kinematics of the species. Until very recently, studies using acoustic monitoring to investigate giant jellyfish were still lacking in China. In this study, we introduce research regarding the acoustic assessment, spatial distribution, and behavioral acoustic telemetry of giant jellyfish to provide a theoretical and scientific basis for the use of acoustic technology for their monitoring and assessment in China. The acoustic target strength of jellyfish is much lower than that of fish because of the lower reflectivity of the jellyfish as a result of its high water content (>95%). However, it is clear now that many species of giant jellyfish are able to produce significant sound scattering at frequencies routinely employed for fisheries assessments. Several studies have shown that the acoustic target strength of giant jellyfish has a positive relationship with its bell diameter. Acoustic monitoring and assessment of giant jellyfish have been more effectively conducted in regions with a dominance of the cnidarian, and in most cases, a combination of nets or video images and other methods were used. Because of the favorable application of a scientific echosounder, high resolution imaging sonar, and ultrasonic pinger in the acoustic monitoring and assessment of giant jellyfish internationally, we recommend their use in China as well. Several suggestions are proposed to support the use and further development of acoustic technology for the study and assessment of the giant jellyfish, including studies of ecological behavior, monitoring, and forecasting and warning systems in key coastal areas to improve the current monitoring systems for giant jellyfish in China.

**Keywords:** giant jellyfish; acoustic monitoring; acoustic assessment; spatial distribution; target strength; acoustic telemetry

Giant jellyfish represent a major group of gelatinous zooplankton and constitute an important component of aquatic ecosystems [1]. Most giant jellyfish belong to the class Scyphozoa within the phylum Cnidaria, with approximately 200 species found in global ocean waters. In Chinese waters, common large jellyfish species include the scyphozoans *Nemopilema nomurai*, *Rhopilema esculentum*, *Cyanea nozakii*, and *Aurelia* spp., as well as hydrozoans of the family Aequoreidae [3-4]. Since the end of the 20th century, frequent giant jellyfish blooms have occurred in multiple sea areas worldwide, causing catastrophic impacts on marine ecosystems, coastal industries, and marine tourism [5-8]. To investigate the bloom mechanisms and develop disaster prevention measures, researchers have conducted extensive monitoring surveys using nets, visual observations, underwater cameras, acoustic technology, and aerial imagery to study jellyfish bloom mechanisms [9-12], dynamic distribution and ecological habits [13-18], fishery resource characteristics [19-22], habitat and prey features [23-28], migration source tracking and numerical modeling [29-32], life history and morphology [33-40], and controlled laboratory experiments [41-45].

Traditional studies of giant jellyfish ecological behavior have primarily relied on net-based monitoring surveys [46-49] and visual observation methods [50-51]. While these approaches provide standardized sampling and can directly reflect horizontal distribution patterns, they lack intuitive data for analyzing underwater swimming behavior and vertical movement patterns. To address these limitations, new technologies such as underwater cameras [52] and aerial imagery [53] have been applied to jellyfish monitoring, each with distinct advantages and disadvantages [54]. With continuous development and refinement of hydroacoustic detection technology, high-resolution sonar, fish finders, and acoustic telemetry have been successfully applied to study Antarctic krill (*Euphausia superba*) [55], Pacific cod (*Gadus macrocephalus*) [56], yellowfin tuna (*Thunnus albacares*) [57], and other economically important species. Acoustic technology enables large-scale, rapid resource surveys and can be applied to monitor fish and zooplankton populations [58-59]. In recent years, acoustic techniques for resource assessment and behavioral tracking of giant jellyfish have been implemented in fisheries-developed countries such as Europe, America, Japan, and Korea, demonstrating promising observational effectiveness and application potential in resource assessment and kinematic studies. However, few published studies on acoustic observation of giant jellyfish behavior have emerged from China. This paper reviews international research on using acoustic technology for jellyfish resource surveys, spatial distribution monitoring, and movement patterns, aiming to provide theoretical foundations and scientific guidance for future acoustic investigations of giant jellyfish in China.

## 1. Research on Acoustic Target Strength and Resource Assessment of Giant Jellyfish

Acoustic survey methods for jellyfish are similar to yet distinct from traditional fish acoustic surveys. Both approaches transmit acoustic pulses into survey

areas, detect backscattered echoes from marine organisms, and receive these signals to assess biological resources. For calculating resource abundance, two primary methods are employed: echo integration and echo counting [60]. Echo integration converts integrated echo values to resource density using target strength, thereby estimating absolute abundance in surveyed areas. Echo counting detects individual echoes to estimate population numbers and community structure [61]. Consequently, target strength directly influences the accuracy of acoustic resource assessments.

In recent years, international researchers have measured acoustic target strength of giant jellyfish using scientific echosounders and conducted resource assessments. High-resolution imaging sonar has also been applied to jellyfish monitoring and assessment with favorable results. Brierley et al. [62] used scientific echosounders with multi-frequency observation techniques combined with net sampling to conduct multiple surveys of the compass jellyfish (*Chrysaora hysoscella*) and *Aequorea aequorea* in Namibian waters, recommending the use of frequency difference techniques (dB difference or MVBS difference) commonly employed to distinguish zooplankton from fish. They established models relating individual target strength to bell diameter for both species at multiple frequencies, revealing positive correlations between bell diameter and target strength. These measurement results were successfully applied to assess large jellyfish resources in the southeastern Atlantic. Mutlu [66] measured target strength of the moon jellyfish (*Aurelia aurita*) in the Black Sea at 120 kHz, establishing relationships between target strength and both bell diameter and wet weight. Brierley et al. [64-65] analyzed target strength of *A. aurita* at four frequencies (18, 38, 120, and 200 kHz). Hirose et al. [68] studied individual acoustic scattering characteristics of *N. nomurai* in Japanese waters using both the distorted-wave Born approximation method and experimental approaches, establishing models relating target strength to biological characteristics at multiple frequencies. They also measured acoustic scattering characteristics of *C. nozakii* and *A. aurita*, finding that the three species exhibited different acoustic scattering signatures at the same frequency. Kang et al. [69] used scientific echosounders at 38 and 120 kHz to measure target strength of *N. nomurai* in Korean waters, finding linear relationships between target strength and bell diameter at both frequencies, with minimal influence from symbiotic jellyfish shrimp. Robertis and Taylor [70] conducted in situ target strength measurements of the sea nettle (*Chrysaora melanaster*) in the Chukchi Sea and Arctic Ocean. Graham et al. [71] used scientific echosounders to assess four scyphozoan species off California: *A. aurita*, *Chrysaora colorata*, *Chrysaora fuscescens*, and *Phacellophora camtschatica*, comparing scattering characteristics at 38, 70, 120, and 200 kHz using both in situ and model-based methods. They established detection thresholds of -80 dB at 38 kHz and -85 dB at 200 kHz. Gorbatsenko et al. [72] conducted multi-frequency acoustic assessments of *Cyanea* spp. and *C. melanaster* on the western Kamchatka shelf, analyzing seasonal bloom patterns and vertical distribution differences between species.

Tomohiko et al. [73] compared acoustic image characteristics of small fish and jel-

lyfish in scientific echosounder data, noting that jellyfish echoes typically appear approximately circular while fish echoes are crescent or wavy-shaped [74]. Han and Uye [75] used high-resolution imaging sonar to monitor *A. aurita* abundance and distribution in Japanese coastal waters, finding that the method provided near-video-quality acoustic images even in low-visibility waters. Although jellyfish acoustic images are less distinct than fish, they can be distinguished by body orientation and gonad characteristics. Combined with net surveys, this method provides accurate assessment of jellyfish abundance and distribution in shallow waters.

presents target strength estimates for various jellyfish species at different frequencies based on in situ measurements, experimental methods, and model calculations.

## 2. Research on Ecological Behavior Characteristics and Spatial Distribution Monitoring

Acoustic technology also demonstrates strong effectiveness in studying giant jellyfish behavior and spatial distribution. Lee et al. [76] used scientific echosounders combined with dual-frequency identification sonar and particle tracking velocimetry to observe vertical distribution and swimming speed of *N. nomurai* in the Yellow Sea, finding they primarily distributed between 10-30 m depth with average swimming speeds of 3.5-6.2 cm/s. Monte Carlo modeling indicated swimming speed was 0.5-0.7 bell diameters per second, providing important parameters for jellyfish migration models. Kaartvedt et al. [77] used two scientific echosounders to study the mesopelagic jellyfish *Periphylla periphylla* in a Norwegian fjord, revealing diverse diel behavior patterns after 15 months of observation. Using upward-facing echosounders at 160 m depth with a detection threshold of -100 dB, they classified four behavioral types: (1) individuals performing diel vertical migration between surface and 100 m depth; (2) smaller jellyfish remaining in the 130-200 m layer, ascending at dusk and descending at dawn; (3) individuals occupying the entire water column at night but restricted to 200 m depth during daytime; and (4) larger individuals showing different patterns. Colombo et al. [67] combined scientific echosounders with underwater cameras to observe *A. aurita* in the Adriatic Sea, demonstrating effective dynamic monitoring of target strength, swimming speed, and diel movement patterns. Acoustic and optical data clearly showed jellyfish below the thermocline during daytime and mixing with mid-water fish at night.

## 3. Application of Ultrasonic Bio-telemetry Technology

Advances in underwater acoustic communication and positioning have enabled acoustic telemetry for tracking marine organism behavior. This technology has been applied in Europe, America, and Japan to study movement patterns and migration characteristics of species including coho salmon (*Oncorhynchus*

*kisutch*), white sharks (*Carcharodon carcharias*), European cuttlefish (*Sepia officinalis*), and Chinese sturgeon (*Acipenser sinensis*) [80-81]. The principle involves attaching small acoustic transmitters (pingers) with temperature, salinity, and depth sensors to study organisms, enabling tracking and positioning via ultrasonic signals. Compared to fish and cephalopods, acoustic telemetry for giant jellyfish presents unique challenges regarding transmitter size, attachment method, and transmission frequency.

Honda et al. [83] tracked swimming depth of *N. nomurai* using pop-up archival tags and ultrasonic pingers, revealing frequent vertical movements between 0.8-176 m depth, with most individuals averaging less than 40 m. Jellyfish in the northern Sea of Japan swam deeper than those in the southern region during autumn, showing relationships with ocean vertical structure. Swimming depth was greater at night than daytime, and deeper at midnight than other nighttime periods. Gordon and Seymour [84] tracked the box jellyfish *Chironex fleckeri* in coastal and estuarine habitats, finding swimming speed and behavior were influenced by time (day/night) and location. Nearshore jellyfish showed similar speeds day and night, while estuarine individuals swam faster at night. Movement rates were consistent across tidal stages nearshore but were highest at mid-tide in estuarine areas. Large aggregations showed movement trends from coastal to estuarine waters.

#### 4. Research Prospects

Over the past decade, Chinese researchers have conducted extensive monitoring surveys on giant jellyfish migration patterns, dynamic distribution, and source tracking in the Bohai, Yellow, and East China Seas using traditional methods. These studies systematically investigated population dynamics, seasonal distribution, and migration patterns, contributing substantially to understanding jellyfish ecology and bloom mechanisms [4, 9, 12-13, 19-21, 27, 40, 47]. Continuous large-scale surveys and controlled laboratory experiments in the East China Sea have examined bloom mechanisms, dynamic distribution patterns, and relationships with fishery resources and zooplankton characteristics [8, 10-11, 16, 18, 22-24, 28, 30-32, 43-45, 50, 85-86]. Research in the Bohai Sea and northern Yellow Sea has focused on life history and reproductive biology of the nuisance jellyfish *C. nozakii* and *A. aurita*, using over a decade of field monitoring and controlled experiments [17, 26, 35-39, 41-42, 48, 87].

While traditional methods have yielded significant contributions, acoustic technology offers effective approaches to supplement net and visual surveys for studying natural ecological behavior, spawning patterns, diel rhythms, and tidal movement. Current research has accumulated target strength data for giant jellyfish, demonstrating that they produce detectable acoustic scattering signals at fisheries survey frequencies [62, 67-69]. Multiple studies confirm positive correlations between target strength and bell diameter at given frequencies [62, 66, 69], providing valuable references for future monitoring. Acoustic monitoring offers advantages including wide coverage, simultaneous horizontal and vertical

distribution assessment, and effectiveness in turbid or dark waters [62, 75].

However, challenges remain. Jellyfish acoustic target strength is significantly weaker than fish due to high water content (>95%). Bell contraction frequency, orientation, and biological characteristics affect scattering [64, 66]. Co-occurring gelatinous organisms like other jellyfish, salps, and appendicularians may contribute to acoustic signals, reducing identification precision [67]. Target strength values can vary substantially among individuals of the same species [68], and different measurement methods may yield varying results [68, 70]. Therefore, published target strength values require validation in field conditions [72]. To minimize interference from noise and weak scatterers, researchers have established species-specific detection thresholds at different frequencies [67, 71, 76]. Multi-frequency techniques [62] and analysis of echo shape differences [73, 74] have been explored for discriminating jellyfish from fish, while high-resolution imaging sonar provides near-video-quality discrimination [75].

Given these technical challenges, acoustic jellyfish monitoring is most effective in waters where jellyfish dominate and typically requires complementary net or video methods [62, 67, 72, 74]. Further research is needed to advance acoustic applications.

International applications demonstrate strong potential for acoustic technology in jellyfish resource assessment and behavioral ecology, providing valuable experience for China. We recommend adapting these methods to Chinese conditions using scientific echosounders, high-resolution imaging sonar, and acoustic telemetry.

**Resource Survey and Assessment:** Acoustic methods offer rapid, efficient sampling with undamaged specimens and data preservation [88]. Since jellyfish occupy multiple water layers, net and visual methods provide limited temporal and spatial coverage. We recommend adopting international acoustic survey experience to develop target strength values for Chinese jellyfish species, using scientific echosounders and imaging sonar combined with traditional methods to accurately assess abundance and distribution, providing scientific support for bloom monitoring and early warning.

**Natural Ecological Behavior Studies:** Acoustic monitoring can provide continuous observations of jellyfish such as *N. nomurai* and *A. aurita* in their primary habitats, tracking vertical distribution, diel migration, seasonal patterns, and spawning behavior. Acoustic telemetry with implanted transmitters could track individual jellyfish during spawning periods, providing fundamental data for understanding natural history and bloom mechanisms.

**Dynamic Monitoring and Early Warning in Key Waters:** Jellyfish blooms severely impact fisheries and tourism, yet current monitoring and warning systems remain inadequate. Systematic acoustic monitoring in high-risk areas, combined with traditional surveys and aerial imagery, could enable continuous, three-dimensional monitoring of jellyfish distribution and abundance, improving early warning capabilities [89].

Acoustic survey and assessment results have gained widespread acceptance for their objectivity and accuracy. Chinese fisheries acoustics research, beginning in the 1990s with applications to South China Sea fish [90], Yangtze River sturgeon [91], and Antarctic krill [92], has expanded to artificial reefs [93], cage culture [94], and open-ocean cephalopods [95], providing a solid foundation for applying acoustic technology to giant jellyfish research. Strengthening acoustic applications in jellyfish monitoring, resource assessment, and behavioral studies is crucial for understanding natural history, bloom mechanisms, and developing effective prevention measures.

## References

- [1] Doyle TK, Houghton JDR, Buckley SM, Hays GC, Davenport J. The broad-scale distribution of five jellyfish species across a temperate coastal environment. *Hydrobiologia*, 2007, 579(1): 29-39.
- [2] Gao SW, Hong HX, Zhang SM. *Fauna Sinica Invertebrata Vol. 27: Phylum Cnidaria: Class Hydrozoa, Subclass Siphonophorae, Class Scyphomedusae*. Beijing: Science Press, 2002.
- [3] Purcell JE, Uye SI, Lo WT. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Marine Ecology Progress Series*, 2007, 350: 153-174.
- [4] Brodeur RD, Sugisaki H, Hunt GL Jr. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. *Marine Ecology Progress Series*, 2002, 233: 89-103.
- [5] Uye SI. Blooms of the giant jellyfish *Nemopilema nomurai*: a threat to the fisheries sustainability of the East Asian Marginal Seas. *Plankton and Benthos Research*, 2008, 3(Suppl.): 125-131.
- [6] Dong ZJ, Liu DY, Keesing JK. Jellyfish blooms in China: dominant species, causes and consequences. *Marine Pollution Bulletin*, 2010, 60(7): 954-963.
- [7] Toyokawa M, Shibata M, Cheng JH, Li HY, Ling JZ, Lin N, Liu ZL, Zhang Y, Shimizu M, Akiyama H. First record of wild ephyrae of the giant jellyfish *Nemopilema nomurai*. *Fisheries Science*, 2012, 78(6): 1213-1218.
- [8] Yoon WD, Lee HE, Han C, Chang SJ, Lee K. Abundance and distribution of *Nemopilema nomurai* (Scyphozoa, Rhizostomeae) in Korean waters in 2005-2013. *Ocean Science Journal*, 2014, 49(3): 183-192.
- [9] Sun S, Zhang F, Li CL, Wang SW, Wang XM, Tao ZC, Wang YT, Zhang GT, Sun XX. Breeding places, population dynamics, and distribution of the giant jellyfish *Nemopilema nomurai* (Scyphozoa: Rhizostomeae) in the Yellow Sea and the East China Sea. *Hydrobiologia*, 2015, 754(1): 59-74.
- [10] Zhang F, Sun S, Jin XS, Li CL. Associations of large jellyfish distributions

with temperature and salinity in the Yellow Sea and East China Sea. *Hydrobiologia*, 2012, 690(1): 81-96.

[11] Huang XG, Huang BQ, Zeng Y, Li SX. Effect of dinoflagellates and diatoms on the feeding response and survival of *Aurelia* sp. polyps. *Hydrobiologia*, 2015, 754(1): 179-188.

[12] Yoon WD, Yang JY, Shim MB, Kang HK. Physical processes influencing the occurrence of the giant jellyfish *Nemopilema nomurai* (Scyphozoa: Rhizostomeae) around Jeju Island, Korea. *Journal of Plankton Research*, 2008, 30(3): 251-260.

[13] Moon JH, Pang IC, Yang JY, Yoon WD. Behavior of the giant jellyfish *Nemopilema nomurai* in the East China and East/Japan Sea during the summer of 2005: a numerical model approach using a particle-tracking experiment. *Journal of Marine Systems*, 2010, 80(1/2): 101-114.

[14] Kawahara M, Uye SI, Ohtsu K, Iizumi H. Unusual population explosion of the giant jellyfish *Nemopilema nomurai* (Scyphozoa: Rhizostomeae) in East Asian waters. *Marine Ecology Progress Series*, 2006, 307: 161-173.

[15] Schiariti A, Kawahara M, Uye S, Mianzan HW. Life cycle of the jellyfish *Lynchnorhiza lucerna* (Scyphozoa: Rhizostomeae). *Marine Biology*, 2008, 156(1): 1-12.

[16] Dong J, Liu CY, Wang YQ, Wang B. Laboratory observations on the life cycle of *Cyanea nozakii* (Semaestomida, Scyphozoa). *Acta Zoologica Sinica*, 2006, 52(2): 389-395.

[17] Dong J, Sun M, Wang B, Liu HY. Comparison of life cycles and morphology of *Cyanea nozakii* and other scyphozoans. *Plankton and Benthos Research*, 2008, 3(Suppl.): 118-124.

[18] Sun M, Dong J, Purcell JE, Li YL, Duan Y, Wang AY, Wang B. Testing the influence of previous-year temperature and food supply on development of *Nemopilema nomurai* blooms. *Hydrobiologia*, 2015, 754(1): 85-96.

[19] Wang N, Li CL. The effect of temperature and food supply on the growth and ontogeny of *Aurelia* sp. 1 ephyrae. *Hydrobiologia*, 2015, 754(1): 157-167.

[20] Feng S, Zhang GT, Sun S, Zhang F, Wang SW, Liu MT. Effects of temperature regime and food supply on asexual reproduction in *Cyanea nozakii* and *Nemopilema nomurai*. *Hydrobiologia*, 2015, 754(1): 201-214.

[21] Brodeur RD, Mills CE, Overland JE, Walters GE, Schumacher JD. Evidence for a substantial increase in gelatinous zooplankton in the Bering Sea, with possible links to climate change. *Fisheries Oceanography*, 1999, 8(4): 296-306.

[22] Purcell JE. Predation on zooplankton by large jellyfish, *Aurelia labiata*, *Cyanea capillata* and *Aequorea aequorea*, in Prince William Sound, Alaska. *Marine Ecology Progress Series*, 2003, 246: 137-152.

- [23] Graham WM, Martin DL, Martin JC. In situ quantification and analysis of large jellyfish using a novel video profiler. *Marine Ecology Progress Series*, 2003, 254: 129-140.
- [24] Houghton JDR, Doyle TK, Davenport J, Hays GC. Developing a simple, rapid method for identifying and monitoring jellyfish aggregations from the air. *Marine Ecology Progress Series*, 2006, 314: 159-170.
- [25] Cutter GR, Renfree JS, Cox MJ, Brierley AS, Demer DA. Modelling three-dimensional directivity of sound scattering by Antarctic krill: progress towards biomass estimation using multibeam sonar. *ICES Journal of Marine Science*, 2009, 66(6): 1245-1251.
- [26] von Szalay PG, Somerton DA, Kotwicky S. Correlating trawl and acoustic data in the eastern Bering Sea: a first step toward improving biomass estimates of walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*). *Fisheries Research*, 2007, 86(1): 77-83.
- [27] Josse E, Dagorn L, Bertrand A. Typology and behaviour of tuna aggregations around fish aggregating devices from acoustic surveys in French Polynesia. *Aquatic Living Resources*, 2000, 13(4): 183-192.
- [28] Simaed Y, Souriasseau M. Diel changes in acoustic and catch estimated krill biomass. *ICES Journal of Marine Science*, 2009, 66(6): 1318-1325.
- [29] Hirose M, Mukai T, Shimura T, Yamamoto J, Iida K. Measurements of specific density of and sound speed in Nomura's jellyfish *Nemopilema nomurai* to estimate their target strength using a theoretical scattering model. *The Journal of the Marine Acoustics Society of Japan*, 2007, 34(2): 109-118.
- [30] Simmonds EJ, MacLennan DN. *Fisheries Acoustics: Theory and Practice*. 2nd ed. Oxford: Blackwell, 2005.
- [31] Brierley AS, Axelsen BE, Buecher E, Sparks CAJ, Boyer HJ, Gibbons MJ. Acoustic observations of jellyfish in the Namibian Benguela. *Marine Ecology Progress Series*, 2001, 210: 55-66.
- [32] Madureira LSP, Everson I, Murphy EJ. Interpretation of acoustic data at two frequencies to discriminate between Antarctic krill (*Euphausia superba* Dana) and other scatterers. *Journal of Plankton Research*, 1993, 15(7): 787-802.
- [33] Brierley AS, Axelsen BE, Boyer DC, Lynam CP, Didcock CA, Boyer HJ, Sparks CAJ, Purcell JE, Gibbons MJ. Single-target echo detections of jellyfish. *ICES Journal of Marine Science*, 2004, 61(3): 383-393.
- [34] Brierley AS, Boyer DS, Axelsen BE, Lynam CP, Sparks CAJ, Boyer HJ, Gibbons MJ. Towards the acoustic estimation of jellyfish abundance. *Marine Ecology Progress Series*, 2005, 295: 105-111.
- [35] Mutlu E. Target strength of the common jellyfish (*Aurelia aurita*): a preliminary experimental study with a dual-beam acoustic system. *ICES Journal of Marine Science*, 1996, 53(2): 309-311.

- [36] Colombo GA, Benović A, Malej A, Lucić D, Makovec T, Onofri V, Acha M, Madirolas A, Mianzan H. Acoustic survey of a jellyfish-dominated ecosystem (Mljet Island, Croatia). *Hydrobiologia*, 2009, 616(1): 99-111.
- [37] Hirose M, Mukai T, Hwang D, Lida K. The acoustic characteristics of three jellyfish species: *Nemopilema nomurai*, *Cyanea nozakii*, and *Aurelia aurita*. *ICES Journal of Marine Science*, 2009, 66(6): 1233-1237.
- [38] Kang D, Park J, Jung SK, Cho S. Estimates of acoustic target strength for giant jellyfish *Nemopilema nomurai* Kishinouye in the coastal Northwest Pacific. *ICES Journal of Marine Science*, 2014, 71(3): 597-603.
- [39] Robertis AD, Taylor K. In situ target strength measurements of the scyphomedusa *Chrysaora melanaster*. *Fisheries Research*, 2014, 153: 18-23.
- [40] Graham TR, Harvey JT, Benson SR, Renfree JS, Demer DA. The acoustic identification and enumeration of scyphozoan jellyfish, prey for leatherback sea turtles (*Dermochelys coriacea*), off central California. *ICES Journal of Marine Science*, 2010, 67(8): 1739-1748.
- [41] Gorbatsenko KM, Nikolayev AV, Figurkin AL, Il'inskii EN. Quantitative composition, distribution and feeding of large jellyfish (Scyphozoa et Hydrozoa) on the west Kamchatka shelf in summer. *Russian Journal of Marine Biology*, 2009, 35(7): 579-592.
- [42] Tomohiko M, Takao Y, Sadayasu K, Matsukura R. Semi-automated acoustic detection of *Nemopilema nomurai* using shaping of high resolution echograms. The 10th Korea-China-Japan Jellyfish International Workshop. Seoul, Korea, 2013.
- [43] Higginbottom I, Woon S, Schneider P. Echoview Technical Manual-Hydroacoustic Data Processing for Standard Stock Assessment Using Echoview. Hobart: Myriax Software Pty Ltd Publication, 2008.
- [44] Han CH, Uye SI. Quantification of the abundance and distribution of the common jellyfish *Aurelia aurita* s.l. with a Dual-frequency IDentification SONar (DIDSON). *Journal of Plankton Research*, 2009, 31(8): 805-814.
- [45] Lee K, Bae BS, Kim IK, Yoon WD. Measurement of swimming speed of giant jellyfish *Nemopilema nomurai* using acoustics and visualization analysis. *Fisheries Science*, 2010, 76(6): 893-899.
- [46] Kaartvedt S, Titelman J, Røstad A, Klevjer TA. Beyond the average: diverse individual migration patterns in a population of mesopelagic jellyfish. *Limnology and Oceanography*, 2011, 56(6): 2189-2199.
- [47] Pinnix WD, Nelson PA, Stutzer G, Wright KA. Residence time and habitat use of Coho salmon in Humboldt Bay, California: an acoustic telemetry study. *Environmental Biology of Fishes*, 2013, 96(2/3): 325-323.
- [48] Klimley AP, Le Boeuf BJ, Cantara KM, Richert JE, Davis SF, Van Sommeran S. Radio-acoustic positioning as a tool for studying site-specific behaviour

of the white shark and other large marine species. *Marine Biology*, 2001, 138(2): 429-446.

[49] Bloor ISM, Wearmouth VJ, Cotterell SP, McHugh MJ, Humphries NE, Jackson EL, Attrill MJ, Sims DW. Movements and behaviour of European common cuttlefish *Sepia officinalis* in English Channel inshore waters: first results from acoustic telemetry. *Journal of Experimental Marine Biology and Ecology*, 2013, 448: 19-27.

[50] Kynard B, Kieffer M. Ultrasonic telemetry of Chinese sturgeon in the Yangtze River. *Journal of Hydroecology*, 1998, 22(3): 211-217.

[51] Downey NJ, Roberts MJ, Baird D. An investigation of the spawning behaviour of the chokka squid *Loligo reynaudii* and the potential effects of temperature using acoustic telemetry. *ICES Journal of Marine Science*, 2010, 67(2): 231-243.

[52] Honda N, Watanabe T, Matsushita Y. Swimming depths of the giant jellyfish *Nemopilema nomurai* investigated using pop-up archival transmitting tags and ultrasonic pingers. *Fisheries Science*, 2009, 75(4): 947-956.

[53] Gordon MR, Seymour JE. Quantifying movement of the tropical Australian cubozoan *Chironex fleckeri* using acoustic telemetry. *Hydrobiologia*, 2009, 616(1): 87-97.

[54] Sun S, Zhang GT. Progress in marine jellyfish ecological research. *Advances in Earth Science*, 2009, 19(2): 121-130.

[55] Dong J, Sun M, Wang B. New understanding of jellyfish bloom mechanisms in the East China Sea. *Oceanologia et Limnologia Sinica*, 2012, 43(3): 406-410.

[56] Wang B, Fang LC, Dong J. Biology of large jellyfish in the Bohai and northern Yellow Seas. *Marine Sciences*, 2006, 28(2): 128-134.

[57] Wang B, Dong J, Li YL. Acoustic assessment of important economic fish resources in the South China Sea. *Marine Fisheries Research*, 1990, 11(3): 1-10.

[58] Chen Y, Liu Y, Jia X. Acoustic assessment of Chinese sturgeon in the Yangtze River. *Journal of Hydroecology*, 2008, 29(1): 25-33.

[59] Zhao X, Wang Y, Li G. Numerical processing of Antarctic krill acoustic images from commercial fish finders. *Progress in Fishery Sciences*, 2012, 33(4): 64-71.

[60] Tang Y, Lin D, Zhang G, Zhang Z, Sasakura T. Testing the tracking of behaviour of a caged *Takifugu rubripes* (Temminck & Schlegel, 1850) using acoustic telemetry. *Journal of Applied Ichthyology*, 2013, 29(6): 1456-1458.

[61] Zhang H, Chen X, Li G. Acoustic assessment techniques for *Sthenoteuthis oualaniensis* in the South China Sea based on light-fall net methods. *Marine Sciences*, 2013, 37(7): 1032-1039.

[62] Zhang H, Chen X, Li G. Resource assessment of *Sthenoteuthis oualaniensis* in the central-southern South China Sea based on fisheries acoustics and light-fall nets. *Journal of Fishery Sciences of China*, 2014, 21(4): 822-831.

[63] Wang B, Dong J, Li YL. Review of acoustic techniques in the monitoring and assessment of giant jellyfish. *Marine Press*, 2013: 1-265.

[64] Wang B, Dong J, Li YL. Progress in research on jellyfish migration patterns and disaster monitoring and warning technology. *Acta Ecologica Sinica*, 2016, 36(10): 3103-3107.

[65] Li YL, Wang B, Dong J. Application of new technologies in jellyfish monitoring. *Ocean Development and Management*, 2014, (4): 38-41.

*Note: Figure translations are in progress. See original paper for figures.*

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