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Passive Acoustic Moniotoring for Estuarine Soniferous Fishes

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Abstract
Hydroacoustics (including active acoustics and passive acoustics) has been broadly used to survey fish aggregations. To date, in passive acoustics, sounds produced by soniferous fishes are primarily used to identify species and to delimit spawning ground. Some progress has been made to estimate number of calling individuals in an aggregation. Passive acoustics requires the use of specific equipment, methods, and computer algorithms to record, process the vocal signals, to track the sound source and possibly to estimate the density of callers.

In 1983, Mok and Gilmore reported their application of passive acoustic technique (or passive sonar technique) to localize the aggregations of soniferous fishes in Indian River Lagoon, Florida and the purpose was to protect their spawning grounds which were assumed to associate with high biological-sound levels. Since then, this approach has been adopted by some fishery biologists as a non-invasive and quick method to monitor the distribution of their aggregations. Despite of some shortcomings of this method, developments in this approach have been made in recent studies to (1) add more environmental data to explain why these aggregations positioned in particular habitats, (2) to design algorithm to estimate in-situ called density.

The purpose of this paper is to introduce our passive acoustic technique for the various studies relating to soniferous aggregations in the Kuroshio region.

Key words: estuary, fish aggregation, hydroacoustics, passive sonar technique, soniferos fish,

That world sea fisheries are in continuous decline is a well documented fact. Effective management is needed both at a regional and also at a global level to protect the remaining fishery resources so that sustainable utilization can become possible. Among marine ecosystems, estuary ecosystems are characterized by high productivity and biological diversity. As a type of ecosystem, estuaries are influenced both by rivers and seas and they may contain various biological niches for nurseries or the maturation of marine animals. Nowadays, many estuaries face anthropogenic threats such as pollution, habitat destruction and overfishing.

In Taiwan, for example, ariids, platycepahlids, sciaenids, teraponids, apogonids, sillaginids, callionymids, leiognathids, and pleuronectids are fish groups inhabiting coasts and estuaries. Interestingly, some of them (e.g., ariids, sciaenids, and teraponids) are soniferous fish—fish which intentionally emit sounds to warn territorial intruders or predators, to attract mates, or to synchronize courtship activity. Some of these groups are important as food (i.e., sciaenids, or croaker and drums) for humans or other marine mammals (e.g., cetaceans). Sounds generated by soniferous fish carry information about these vocal individuals: their species identity, size, sex, social status, reproductive state, location, or even their immediate local environmental conditions (e.g., water temperature)

To achieve the goal of the sustainable utilization of fishery resources, data on the target species' life cycles, population dynamics, spatial and temporal distributions, stock assessments, and spawning grounds are required. These data are collected by various means including active fishery sonar, multi-beam sonar, and the capture of specimens at various developmental states using trawls, traps or set nets. Hydroacoustics (including active acoustics and passive acoustics) have been broadly used to survey fish aggregations. Active acoustics (or active sonar) is a method for locating an underwater target by measuring its distance and direction by the reflections of an observer-sent sound signal which is bounced off of it. Passive acoustics (or passive sonar), on the other hand, does not use sound radiated by the observer but depends on detecting sounds generated by its targets such as cruising submarines or vocalizing cetaceans and fishes.

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Passive acoustics has some benefits over active sonar for fishery research including the remote sensing of fish distributions over horizontal distances; the non-invasive sampling of the animals and the non-destructive sampling of the habitats; effectiveness even at shallow depths where active sonar cannot be used; and effectiveness in detecting individuals or groups of variable sizes. Lowerre-Barbieri *et al*. (2008) found that the use of passive acoustics is the best method for covering large areas and for sampling habitats where traditional capture methods cannot be used. They also pointed out that the biggest disadvantage of this method was that of sound interference by boats or water conditions (rushing currents, waves, high winds), which made it somewhat more difficult to use offshore. However, these disadvantages can be minimized if the survey is conducted under favorable sea conditions. To attract females to lay their eggs, males emit sounds. For sciaenids, large choral aggregations of males form in the spawning season. Because of this, passive acoustics has an additional disadvantage, the information it provides is often linked to the mature males. Due to this, however, it is useful in delimitating spawning grounds but not in estimating the numbers of the aggregated mature males and females.

Among the soniferous groups, Sciaenidae has received most attention because of their high species diversity (about 270 species worldwide; Ramcharitar *et al*. 2006) and commercial value. Evidence was presented in some studies suggesting that the seasonal mating calls were directly associated with spawning activity. To further understand soniferous sciaenid aggregation, the following questions are of great concern. What types of sounds do they make under various internal and external conditions? Why, when and where do they produce the sounds? What is the social effect on vocal activity (i.e., the number of individuals engaged in a spawning aggregation)? As many sciaenids are now well suited for marine culture, a lot of important information, which could be useful for passive acoustic techniques, can be obtained through experiments using cultured fish.

Stridulation, drumming, and hydrodynamics are the main ways fish produce sounds. The first method involves rubbing together hard bony body structures; the second method involves the fast twitching of the sonic muscles near the swim bladder, which serves as an amplifier; and the third method involves a temporal change in the relative movement between the water and the fish's body parts. The majority of fish sounds are lower than 1000 Hz. As the target sounds produced by fish are in the low frequency range (around 100 Hz), an omnidirectional hydrophone with a frequency range of 20Hz - 16000 Hz is suitable for surveying. Recordings should be made for at least a 30-s period on a digital audio tape-recorder (DAT), set at a sample rate of 44.1 KHZ (to capture sounds with a maximum frequency of 20 KHz; Fig. 1).

Fig. 1 The sound recording system contains a hydrophone unit (a hydrophone and amplifier) and a digital recorder (Underwater ambient biological noise can be recorded using the portable recording system and the locality of the monitoring stations is recorded using GPS.)

Peak sound production in sciaenids usually occurs in the evening (e.g., Saucier and Baltz 1993; Lowerre-Barbieri *et al*. 2003); therefore, recordings should be made during this window of peak sound production which may only last for a few hours. Field recordings of sounds are made in the surveyed region either at pre-selected sites representing various habitats and depths, or in all the grids covering the region. A hydrophone is lowered to a particular depth (e.g., for demersal fishes, it should be placed close to the seafloor). Additional data from other depths (e.g., mid-water and slightly above the seafloor) can also be recorded. As temporal variations in vocalization have been noted, it is necessary to account for obvious differences among the recording sites due to the times when signals are sampled. To do so, only a short recording session is made at each site and one should reach the next site as soon as possible. To characterize the spawning habitat, hydrographic data (surface and bottom water temperatures, salinity, dissolved oxygen, and bottom type) should be recorded during the field sound recording.

The recorded sound files were analyzed using commercial software (e.g., Avisoft, Raven, or Spectrogram 11, etc.). The following temporal and spectra characteristics of the sound waves were measured: the call duration in ms (measured as the time interval between the onset of one pulse train and its end); the number of pulses in a call; the pulse length in ms; the pulse period in ms (measured as the average peak to peak interval between consecutive pulse units in the train); the number of peaks in a pulse; the repetition rate (number of pulses/min); the inter-pulse interval (measured as the duration between the end and the beginning of two consecutive pulses in a pulse train) and the dominant frequency (in Hz) which represents the most intense frequency of the individual sound pulses (Connaughton *et al*., 2000; Lagardere and Marianai, 2006; Figs. 2, 3).

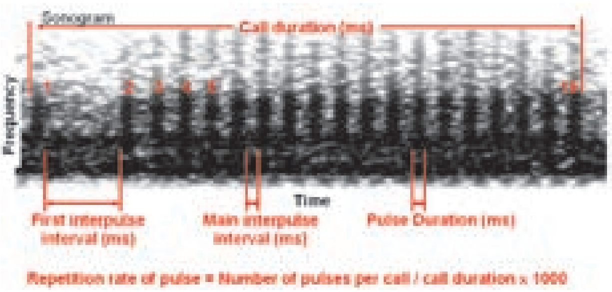

Fig. 2 Definition of the acoustic parameters used to describe the physical characteristics of a bigsnout croaker call (Note the longer 1st interpulse interval: Lin *et al*., 2007).

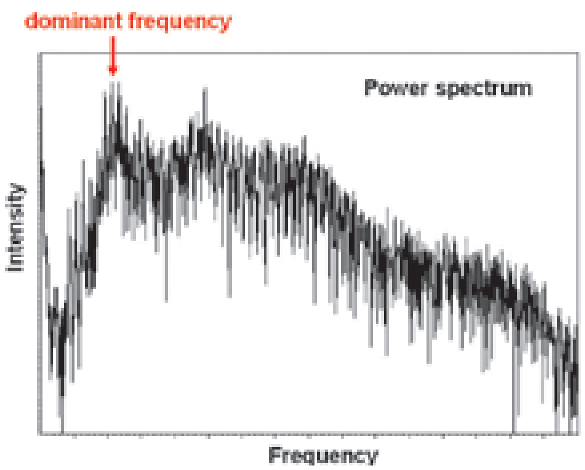

Fig. 3 A power spectrum of a pulse in a call

To identify the producers of the sound types taken from the natural environment, a detailed sound archive, including the sounds emitted by the species in the surveyed region, is needed. One problem is that there is no confirmed similarity between the sounds emitted under hand-held disturbance and those emitted under natural conditions. As such, sounds produced under the former condition may not be valid for identifying those produced in the latter condition. Lin *et al*. (2007) have provided some evidence that the sounds from both conditions share unique characteristics; this finding grants a value to the disturbance sound to identify wild sound types. Interspecific calls can be distinguished from those of other soniferous fish based on pulse duration, repetition rate, and dominant frequency range (Walters et al. 2009). The inter-pulse interval can also be an informative parameter for species distinction (Lin *et al*. 2007).

In 1983, Mok and Gilmore reported on their application of passive acoustic techniques (or passive sonar technique) to localize the aggregations of three sciaenid species (i.e., the spotted seatrout, silver perch, and black drum) in the Indian River Lagoon, Florida, U.S.A. These are commercial and recreational species in the United States of America. The final purpose of the survey was to protect the spawning grounds which were assumed to correlate with areas of high biological-sound levels.

At an early stage of the passive acoustic survey, sound categories including individual, small group and large group sounds were assigned to each recording site or grid so that the aggregation of sounds could be localized (Fig. 4). These sites were correlated to underwater topography (e.g., Mok and Gilmore, 1983). Since then, the approach of the passive acoustic technique has been adopted by some fishery biologists as a non-invasive and quick method to monitor the distribution of the aggregations of mature individuals. Despite the above-mentioned shortcomings, developments in this approach have been made in more recent studies in which (1) more environmental data are taken into account to explain why these aggregations were positioned in particular habitats, (2) new algorithms were developed to estimate in-situ caller density, etc. To date, passive acoustics is not only used primarily to identify soniferous species and delimit spawning grounds but also to estimate the number of calling individuals in an aggregation, and to localize and track sound sources more accurately. New findings have shown that, for example, the long-term stability of spawning site locations, with the principal spawning sites identified by Mok and Gilmore (1983) being used for over 20 years (Gilmore 2002). In addition, the mere presence of the sounds does not necessarily indicate actual spawning events; Lowerre-Barbieri *et al*. (2008) noted that red drum males make calls with 4 or fewer pulses per call without associated spawning, and that spawning took place only after longer calls had occurred (i.e., at least 8 pulses/call). This new finding suggests that acoustic information can be used to predict the in-situ reproductive state of the vocalizing target aggregation. Recent studies add more environmental parameters to the picture so that factors determining spawning habitats can be discovered. The presence of submerged aquatic vegetation, proximity to the shoreline, and a high dissolved oxygen content were positively correlated with the spawning areas of the spotted sea-trout, Cynoscion nebulosus (Walters *et al*., 2009). Spotted sea-trout and red drum seem to prefer to spawn in relatively deeper environments (pers. unpubl. data; Lowerre-Barbieri *et al*., 2008)

Most of the works involving passive acoustic surveys have been done in bays or lagoons in the Atlantic region. The purpose of this presentation is to introduce this method and hopefully see it applied to study soniferous fish aggregations in the western Pacific region, including the Kuroshio region, and to have it extended to the study of offshore waters. Mok *et al*. (2009) successfully applied this method to offshore waters. In addition, despite the majority of sciaenids being marine species, some live in brackish and fresh water. Many species are reported in the Philippines. The estuaries of the Cagayan River, which is the longest and largest river in the Philippine Archipelago, and the Pulangi River, the second largest river system in the Philippines, are expected to be sites for sciaenid aggregations.

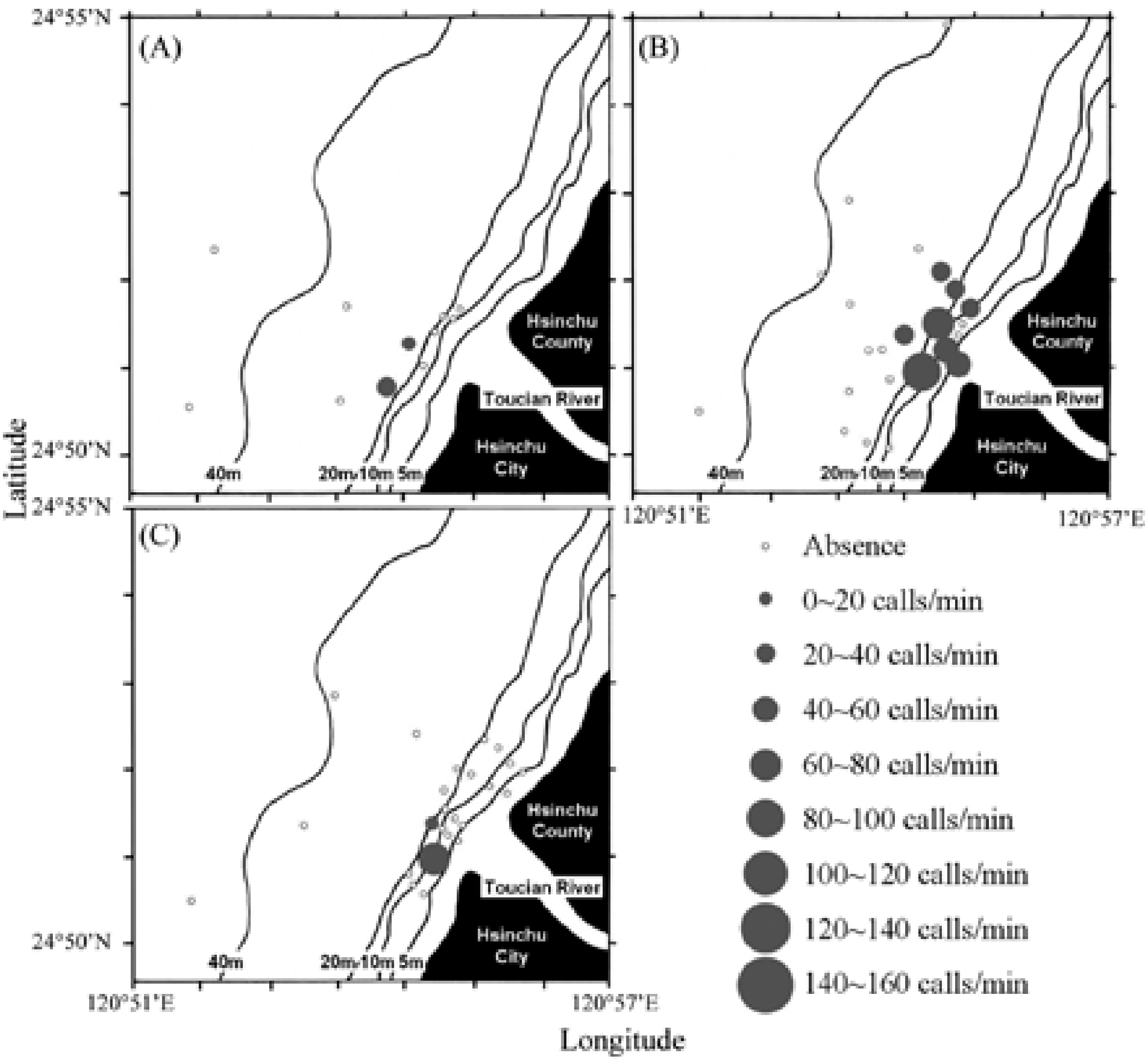

Fig. 4 Distribution of the big-snout croaker's sounds in the Toucian River survey area, Taiwan
Nine ranking categories (number of calls per minute) were used to show field drumming-sound intensity. Open circle: absence of sounds; solid circle: presence of sounds. Larger solid circles indicate more sounds. (A) spring (March 26, 2003); (B) summer (July 12, 2003); (C) autumn (October 12, 2003).

References

Connaughton, M.A., Taylor, M.H., and M.L. Fine. 2000. Effects of fish size and temperature on weakfish disturbance calls: implications for the mechanism of sound generation. *J. Exp. Biol.* 203:1503-1512.

Gannon, D.P. 2008. Passive acoustic techniques in fisheries sciences: a review and prospectus. *Tran. Amer. Fish. Soc.* 137: 638-656.

Gilmore, R.G. 2002. Passive acoustic transects: mating calls and spawning ecology in East Florida sciaenids. In Listening to fish: Proceedings of the international workshop on the applications of passive acoustics to fisheries. April 8-10, 2002 (Rountree, R.A., Goudey, C. and Hawkins, T., eds), pp. 1-10. *MIT Sea Grant Technical Report* 03-2. Dedham, MA: Sea Grant Publications.

Lagardere, J.P. and A. Mariani. 2006. Spawning sounds in meager *Argyrosomus regius* recorded in the Gironde estuary, *France. J. Fish Biol.* 69: 1697-1708.

Lin, Y. C., Mok, H. K., and Huang, B. Q. (2007). Sound characteristics of big-snout croaker, *Johnius macrorhynus* (Sciaenidae). *J. Acoust. Soc. Am.* 121, 586-593.

Lowerre-Barbieri, S.K., L.R. Barbieri, and J.R. Flanders. 2008. Use of passive acoustics to determine red drum spawning in George waters. *Trans. Amer. Fish. Soc.* 137:562-575.

Mok, H.K. and R. G. Gilmore. 1983. Analysis of sound production in estuarine aggregations of *Pogonias cromis, Bairdiella chrysoura*, and *Cynoscion nebulosus* (Sciaenidae). *Bull. Inst. Zool.*, Academia Sinica 22: 157-186.

Mok, H.K., H.Y. Yu, J.P. Ueng, and R.C. Wei. 2009. Characterization of sounds of the blackspotted croaker *Protonibea diacanthus* (Sciaenidae) and localization of its spawning sites in estuarine coastal waters of Taiwan. *Zool. Studies* 48: 325-333.

Ramcharitar, J., D.P. Gannon, A.N. Popper. 2006. Bioacoustics of fishes of the family Sciaenidae (croakers and drums). *Trans. Amer. Fish. Soc.* 135: 1409-1431.

Saucier, M.H. and D.M. Baltz. 1993. Spawning site selection by spotted seatrout, *Cynoscion nebulosus*, and black drum, *Pogonias cromis*, in Louisiana. *Enviro. Biol. Fish.* 36:257-272.

Walters, S.L., S. Lowerre-Barbieri, J. Bickford, D. Mann. 2009. Using a passive acoustic survey to identify spotted seatrout spawning sites and associated habitat in Tampa Bay, Florida. *Trans. Amer. Fish. Soc.* 138: 88-98.

Supplemental Reference

Studies on the Population and Acoustic Signals of Bryde’s Whales *(Balaenoptera edeni)* in Tosa Bay, Japan

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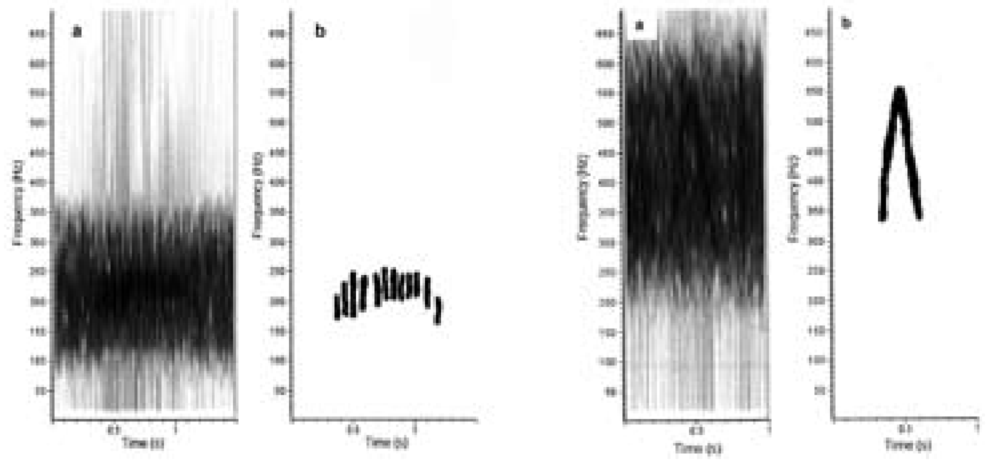
Abstract

Bryde’s whales (*Balaenoptera edeni*) is a species of baleen whales widely distributed throughout the tropical and temperate waters and does not migrate for long distance. Phylogenetically, the population in Tosa Bay, which includes about 43 individuals identified, belong to the East China Sea Stock and it behaves between migratory and non-migratory forms. Studies on acoustic signal and individual identification could help us understand Bryde’s whales in Tosa Bay more. Between August and December 2008, two sound types were recorded and analyzed. The sound type Be8a was considered as feeding call, while the nonpulsed moan was considered associated with mother-calf communication during separation. In this study period, other 31 individuals were identified and added into the catalogue. Bryde’s whales are distributed very limited. Concentration of individuals was found in centaral Tosa Bay between spring and early autumn and it shifted southwestern in late autumn and winter. This study suggested that the East China Sea Stock may separate into two or more communities and the population in Tosa Bay belongs to the northern community.



Sonograms of sound type Be8a from adult Bryde’s whales(left) and of nonpulsed moan from a mother-calf pair(light)

Note: a) The sonogram was the printout of a sound analysis software. b) A diagrammatic illustration of the sonogram converted from a).

Source: MS thesis by Pai-Ho Chiu submitted to National Sun Yat-sen University, 2009.

Photo: Ms. Chiu with her advisor, Dr. Mok