BIOMASS AND SPATIAL DISTRIBUTION ESTIMATES OF HAIRTAIL (*TRICHIURUS JAPONICUS*) IN THE NORTHERN WATERS OF TAIWAN

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Abstract. In the East China Sea, the population structure of hairtail has varied for the last 20–30 years because of high intensity of fishing pressure. Therefore, for the sustainable management of hairtail, a conservative measure is required on the basis of scientific research. Acoustic transect line survey was conducted from 10 to 17 Dec 2019 in the northern sea of Taiwan along with 7 pole and line fishing and 1 trawl sampling to estimate the biomass and spatial distributional characteristics of hairtail. Two fishing gears had very different results. Thus, for hairtail allocation, three interpretation scenarios of low, medium, and high in total backscatter were considered. Consequently, the hairtail biomass in three scenarios were to be 5286 (30%), 7048 (40%), and 8810 tons (50%), respectively. Acoustic data from a long coastal line and three lines at a similar location were extracted to examine fish distributional characteristics. Lastly interpolated water temperature and salinity with backscatters were compared. This study can support in designing an integrated acoustic trawl survey next year, as well as the sustainable hairtail resource management.
Keywords: *hairtail, biomass, fish school property, water temperature, fishing gear*

Introduction

Largehead hairtail (*Trichiurus japonicus*) is widely distributed throughout the tropical and temperate regions of the world and commonly inhabit in muddy sand bottoms of the continental shelf. It is one of the most commercially and ecologically important fish species in Taiwan, Korea, Japan, and China (Kim and Rho, 2002; Liu et al., 2009). It is characterized by extensive migration, year-around long spawning period, and a slow growing species with a life span of up to nine years. It is a long and slender fish and a swimbladder-bearing, and feeds on crustaceans and a variety of small fishes including its own juvenile. It serves as one of the top predators in the ecosystem (Wu, 1991; Duarte and Garc, 1999; Froese and Pauly, 2019). In the East China Sea, it is a primary fish species incorporating a large proportion of the fishery productivity. In particular, it is an important commercial marine species in Taiwanese fisheries.

The East China Sea is one of the typical over-exploited ecosystems in the world where a number of fish populations are overfished. Hairtail has been extensively exploited since

the 1950s in the East China Sea, its annual catch in Taiwan was approximately 16,000 tons in recent years. For targeting hairtail in northeastern water off Taiwan, the main fishing season is from September to December, sometimes until January or February of the following year. Because of high intensity of fishing pressure and overfishing, the population structure of hairtail has been varied for the last 20–30 years. It has had a declining trend in hairtail population and its mean population age (Zhou et al., 2002; Panhwar et al., 2018). Therefore, for the sustainable management of hairtail, a conservative measure is required on the basis of scientific research. First of all, reliable estimates of the biomass and spatial distribution of hairtail are important prerequisites. Meanwhile, the changes in spatial distribution of fish can have a significant impact on species interactions. The spatial distributional property of fish is closely connected to fish population since its elements have a positive relationship with fish population (Hutchings, 1996; Reuchlin-Hugenholtz et al., 2015). Thus, the spatial distributional information has a considerable potential to enhance hairtail resource management plans. Fisheries managers can take steps such as biomass limit or certain time period of fishing ban to attain the maintenance of a healthy and productive population of commercially exploited hairtail.

To understand the spatial distribution and biomass of fishery resources, scientific echosounders have been widely used globally (Zhang et al., 2014; Kang et al., 2015; Park et al., 2016). Using an echosounder has great advantages. It covers relatively a wide area in a short time, and produces accurate and precise acoustic data that lead to valuable information on fish abundance and their distributional properties throughout water columns (Simmonds and MacLennan, 2005). To date, the estimation of the biomass and spatial distribution of hairtail off northern Taiwan had not been studied. In Taiwan, a few studies using an echosounder have been done. A couple of studies were to detect gas plume images on the mud volcano a 38 kHz echo sounder to understand the distribution of relevant gas emissions (Hsu et al., 2013) and to realize the intensity of gas emissions and the magnitude of tremors in relation to tidal range (Hsu et al., 2018). For targeting marine fauna in water column, some research was done. For example, acoustic sound scattering layers and their moving speed in northeastern Taiwan were observed using a 38 kHz echosounder (Lee et al., 2011), anchovy larvae were detected by a 200 kHz commercial echosounder to associate with environmental factors (Lee et al., 1995), and commercially important fish species such as skipjack, round scad, horse mackerel, anchovy and larval fish were acoustically and statistically identified using a 420 kHz echosounder (Lu and Lee, 1995). However, there was no study for aiming hairtail using an echosounder. It is the first time to conduct an acoustic survey for targeting hairtail in Taiwan. We hope that the result of this study can assist in designing a next acoustic survey for a better management of the species. The objective of this study is to estimate the biomass and spatial distributional characteristics of hairtail in the northern water of Taiwan.

Materials and Methods

Field survey

Acoustic transect line survey was conducted from 10 Dec 2019 to 17 Dec 2019 in the northern sea of Taiwan. It included 13 parallel transect lines (*Fig. 1*). The green line was entire voyage line. An average transect line was 7.5 nm and a total survey area was 238.2 nm^2. Acoustic data were collected on RV Fishery Research 2 (340 tons) using a

calibrated scientific echosounder with three frequencies (Simrad EK60, 38, 120, and 200 kHz). Three transducers had the same norminal beam width of 7°. The sounder sampled the water column at ping rate of 3.3 Hz with a pulse duration of 0.256 ms.
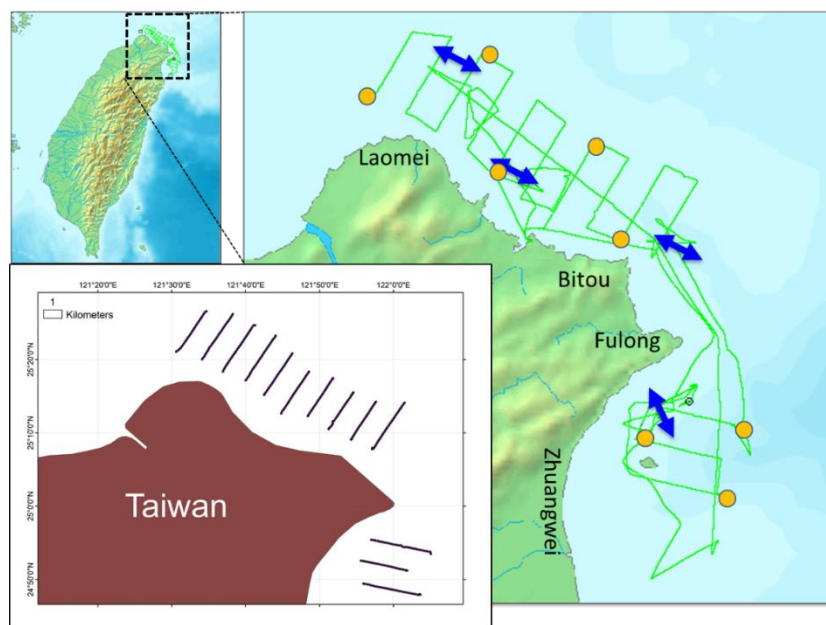
Figure 1. Survey area including entire voyage line (green line), biological sampling sites (dark blue arrow), and CTD sites (yellow circle). The bottom panel shows 13 transect lines

The conductivity, temperature, depth sensor (CTD, SBE 911plus, Sea-Bird Scientific) was used to obtain oceanographic information. A total of 8 CTD profiles were recorded. Four CTD stations were located close to the coast (start of the transect line) and other 4 stations were near offshore (end of the transect line). The descent and ascent speeds of the CTD measurement were not more than 1 m/s, and only ascending data were used. The vertical resolution was approximately 0.3 m.

The biological sampling such as pole and line fishing and trawling was performed in concurrent with acoustic survey (*Fig. 1*). For trawl gear, head rope was 8.4 m, ground rope was 10.0 m, and side rope was 45.5 m. The mesh size of the cod-end was 30 mm. The towing speed was 6 m/s. For pole and line fishing, hooks were reached near sea bottom in daytime and approximately 50 m in nighttime, respectively. The bait was sliced saury. The detail biological sampling such as the time, duration, catch weight, and fishing gear are shown in *Table 1*. Seven pole and line fishings were conducted while only one trawling was performed. The duration of trawl was one hour and average duration of pole and line fishing was 5 hours 57 minutes. The caught samples were separated by fish species and the total weight of each species was weighed. Total length and body weight of each species, with snout-anus length for only hairtail species, in representative sampled numbers were measured.

Data processing

Acoustic raw data (38 kHz) of the echosounder were processed using the Echoview ver. 10 (Echoview Software Pty Ltd). The minimum threshold of the volume back scattering strength (S_V) was set as of −75 dB. To eliminate noise signals by ring down

and surface bubbles, features of the 'threshold offset' and 'line pick' in Echoview were used. To define the seabed line, a 'best bottom candidate algorithm' was applied, and then visually inspected and edited. On S_V echogram, attenuated signals were often observed. The attenuated signal removal algorithm described in Ryan et al. (2015) was applied to set attenuated signals as no-data. It differentiates and adjusts pings which present an attenuated signal when compared to surrounding pings. To increase signal to noise ratio, background noise removal algorithm introduced in de Robertis and Higginbottom (2007) was used. It calculates the background noise for each ping and subtracts it from each data point (Echoview, 2020).

Table 1. *Date, time, total catch and fishing gear of biological sampling*

No	Date	Start time	End time	Duration	Total catch (kg)	Gear type
1	10 Dec	18:13	23:20	5:07	9.7	Pole and line
2	13 Dec	18:02	0:00	5:58	13.2	Pole and line
3	14 Dec	13:24	14:24	1:00	9.1	Trawl
4	14 Dec	15:00	18:00	3:00	8.1	Pole and line
5	14 Dec	18:00	23:00	5:00	21.4	Pole and line
6	16 Dec	16:55	23:00	6:05	0.9	Pole and line
7	17 Dec	6:31	18:00	11:29	3.8	Pole and line
8	17 Dec	18:00	23:00	5:00	5.0	Pole and line

For estimating the hairtail biomass, NASC (Nautical Area Scattering Coefficient, dB re m^2/nm^2) of cell (500 m in horizontal and 250 m in vertical which was deeper than seabed) in transect lines was exported. Acoustic data on the transect line for estimating the hairtail biomass were collected during daytime. Except for 13 transect lines, three voyage lines at a similar location off from Bitou to Fulong (Gongliao District) and relatively one long voyage line off from Laomei to Zhuangwei were selected to understand the fish distributional characteristics (*Fig. 1*). The former line was named as 'three lines' and the latter line was called as 'coastal line'. In especial, information on hotspot where fish are aggregated on the coastal line is beneficial for fishery resources management. To examine the fish distributional characteristics, NASC of a cell (500 m horizontally and 10 m vertically) in three lines and coastal line was exported, respectively.

Hairtail biomass estimation

To estimate hairtail biomass, first of all, the hairtail biomass (ton) per transect line (Bt) was calculated using the *equation (1)*.

$$Bt = \frac{\overline{S_{At}} \cdot \frac{\overline{W}}{1000} \cdot A_t}{4 \cdot \pi \cdot 10^{\frac{\overline{TS}}{10}}}$$
(Eq.1)

where $\overline{S_{At}}$ (m^2/nm^2) is the mean return acoustic signal, that is the linear domain of NASC for transect t, A_t is per transect survey area (nm^2), $\overline{TS}$ is mean target strength (dB re m^2) of hairtail and $\overline{W}$ is mean weight of hairtail (kg). The target strength (TS) for hairtail was adapted from Zhao (2006).

$$TS = 20 \log La - 68.3$$
(Eq.2)

where, La is anal length (cm). By applying the average anal length (21.8 cm) of hairtail from the pole and line fishings and trawling, the TS of hairtail became −41.5 dB. The average body weight of hairtail from biological samplings was 187.1 g.

$$Biomass = \sum_{i=1}^{n} Bt_i \qquad (Eq.3)$$

The per-transect biomass (Bt_i) was summed to give an estimate of biomass for the total survey area. To calculate the area based on a transect line, the length of transect line and distance between two lines were estimated using Google earth (Google). Sampling variance was computed using *equation (4) and (5)*, and is a measure of survey repeatability, showing variability between transect lines (Jolly and Hampton, 1990). If a fish aggregation is densely distributed in one or two transect lines, the sampling variance will be high.

$$\overline{(S_A)_i} = \frac{\sum_{i=1}^{n}(S_A)_i \cdot L_i}{\sum_{i=1}^{n} L_i} \qquad (Eq.4)$$

$$Var\overline{(S_A)_i} = \frac{1}{n \cdot (n-1)} \frac{[\sum_{i=1}^{n}(L_i)^2[\overline{(S_A)_i} - \overline{S_A}]]^2}{[\sum_{i=1}^{n} L_i]^2} \qquad (Eq.5)$$

where $\overline{(S_A)_i}$ is the mean S_A for transect line i, L_i is the length of transect line i, and n is the total number of transect lines.

Fish distributional characteristics

Fish aggregations were observed on the coastal line which was recorded from 23:23 on 16 Dec 2019 to 04:51 on 17 Dec 2019. The fish school detection module imbedded the SHAPES (the shoal analysis and patch estimation system) algorithm in the Echoview was applied (Coetzee, 2000; Echoview, 2020). Two minimum thresholds (−75 dB and −70 dB) were used. The fish schools were determined by defining the boundaries of fish school like regions. Properties of these regions were examined to extract diverse characteristics of the fish schools such as S_V, thickness, length, distributional depth, area, center of mass, inertia, and aggregation index. Various studies were conducted using the characteristics of detected fish schools (Barange, 1994; Scalabrin et al., 1996; Diner, 2001; Urmy et al., 2012; Kang et al., 2016; Echoview, 2020). The description and computation of the fish school characteristics can be referred in the above references. In particular, the center of mass (CM) is the average of all depths sampled by weighting with their S_V values. Inertia (I) is a metric of the spread of backscatter, and it increases when more backscatter is farther away from the CM. The aggregation index (AI) is a metric of the aggregation of backscatter. When backscatter is uniformly distributed, AI will be low; when backscatter is formed in dense clusters, it will be higher.

$$CM = \frac{\int zSv(z)}{\int Sv(z)} \qquad (Eq.6)$$

$$I = \frac{\int (z-CM)^2 Sv(z)dz}{\int Sv(z)dz} \qquad (Eq.7)$$

$$AI = \frac{\int Sv(z)^2 dz}{\left(\int Sv(z)dz\right)^2} \qquad (Eq.8)$$

where z is the depth (m) of a sample in the region. $S_V(z)$ is the sample volume backscattering coefficient at z.

Statistical analysis

Three lines, which were located in a similar location, were divided into outer line, middle line, and inner line on the basis of their positions. Outer line, middle line and inner line were collected from 23:14, 13 Dec to 01:25, 14 Dec, from 01:43, 17 Dec to 02:54, 17 Dec, and from 03:26, 15 Dec to 05:00, 15 Dec, respectively. The locations of three lines were very close each other. However, their collected times were different although they all were recorded at night. To examine whether the acoustic backscatters among three lines were same or not, one-way analysis of variance (ANOVA) along with post-hoc test was applied. To determine whether significant differences of fish distributional characteristics existed between two threshold values applied, a nonparametric test (Mann-Whitney U test) was performed. Statistical analyses were performed using SPSS ver. 19 (IBM).

Interpolation of water temperature and salinity

Kriging interpolation method in Surfer ver. 8.01 (Golden Software, LLC) was used to visualize the vertical profile of temperature and salinity. Default setting properties of the Kriging interpolation was applied. Its fundamental principle is depending upon the values of adjacent variables, using its exhibit variogram, which is a description of the surface's roughness based quantitatively and statistically, to reflect the inner connection among regionalized variables, and combined with the original data to estimate regional unknown sampling point value. It is a sort of optimal unbiased estimation method (Xiao et al., 2016).

Results

Catch from biological sampling

Surprisingly, only hairtail species was caught by 7 pole and line fishings. Averaged total length, averaged body weight, and averaged snout-anus length were 732.7 mm, 193.1 g, and 236.9 mm, respectively. Averaged total lengths in day time and night time were 742.9 and 727.6 mm, respectively. Averaged snout-anus lengths in day time and night time were 206.3 mm and 197.4 mm, respectively (*Table 2*). From one trawling, hairtail accounted for 7% out of total caught weight. Averaged snout-anus length and averaged body weight were 199.6 mm and 115.5 g, respectively. In addition, no acoustic raw data was recorded during the last biological sampling time (18:00–23:00, 17 Dec).

Hairtail biomass estimation

By the pole and line fishing, only hairtail was caught, and by trawling only 7% of hairtail from total catch was confirmed (*Table 3*). Two different fishing gears had very different results. Thus, it was extremely difficult to determine how much backscatter should be allocated for hairtail species. Inevitably, an assumption with regard to the allocation of hairtail should be made to estimate its biomass. Three interpretation scenarios of low, medium, high such as 30%, 40%, and 50% of total backscatter were considered. Acoustic survey data was echointegrated for each three interpretation scenario using *equations (1) – (3)*. As a result, the hairtail biomass in three interpretation

scenarios were estimated 5,286 tons (30%), 7,048 tons (40%), and 8,810 tons (50%), respectively (*Table 4*). The sampling variance calculated using *equation (4) and (5)* was 0.4.

Table 2. Total length, snout-anus length, and body weight of pole and line fishing samples

| Date	Time	Total length (mm)			Snout-anus length (mm)			Body weight (g)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
10/12/2019	Night	722.4	633	825	225.9	195.1	262.1	164.8	94	238
13/12/2019	Night	700.9	480	927	221.9	173.8	288.0	159.5	71	288
13/12/2019	Night	709.7	552	880	231.6	177.3	302.8	175.9	84	348
14/12/2019	Day	769.2	673	869	258.3	203.2	335.0	240.5	110	464
14/12/2019	Day	797.7	728	918	260.8	224.6	306.5	257.7	159	406
14/12/2019	Night	706.3	612	834	219.3	191.4	282.4	163.0	91	322
14/12/2019	Night	713.1	570	845	227.7	175.4	276.3	172.3	100	346
16/12/2019	Night	805.0	775	860	282.4	247.6	310.0	314.8	172	415
17/12/2019	Day	698.8	620	795	221.9	199.6	254.3	155.7	106	263
17/12/2019	Day	706.1	631	775	227.2	197.9	260.7	158.8	101	231
17/12/2019	Night	702.9	585	792	219.1	185.6	244.8	145.3	99	212
17/12/2019	Night	760.3	730	801	246.9	232.5	258.1	208.8	160	272
Average value		732.7	632.4	843.4	236.9	200.3	281.8	193.1	112.3	317.1

Table 3. Caught weight by trawling based on fish species and their percentages. Note that it is shown above 5% of total weight

Common name	Caught weight (g)	Percentage of total weight (%)
Japanese jack mackerel	2671.5	27.2
Horsehead tilefish	1001.9	10.2
Yellow-spotted skate	705.5	7.2
Hairtail	692.9	7.0
Japanese goatfish	673.8	6.9
Silver pomfret	643.2	6.5
Spotted moray	636.2	6.5

Table 4. Estimated hairtail biomass per transect line in three interpretation scenarios

Line	NASC (m²/nm²)	Area (nm²)	Biomass (ton)	30% scenario	40% scenario	50% scenario
T1	65.9	25.2	350	105	140	175
T2	105.5	18.5	413	124	165	207
T3	203.1	19.1	820	246	328	410
T4	61.5	18.1	235	71	94	118
T5	80.2	20.5	347	104	139	173
T6	71.6	19.1	289	87	116	144
T7	177.5	14.6	546	164	218	273
T8	224.6	13.8	653	196	261	326
T9	188.9	15.0	597	179	239	299
T10	631.5	13.1	1,744	523	698	872
T11	635.1	21.5	2,885	865	1,154	1,442
T12	113.4	21.9	525	158	210	263
T13	2167.1	17.9	8,216	2,465	3,286	4,108

Thematic map of NASC is shown in *Fig. 2*. East part off Keelung city presented rather high NASC than in west part. In particular, the last transect line off Yilan county (below 24°50'N) had the highest NASC. The 9th and 10th transect lines off Gongliao district and the 11th transect line off Yilan county occurred high NASC.
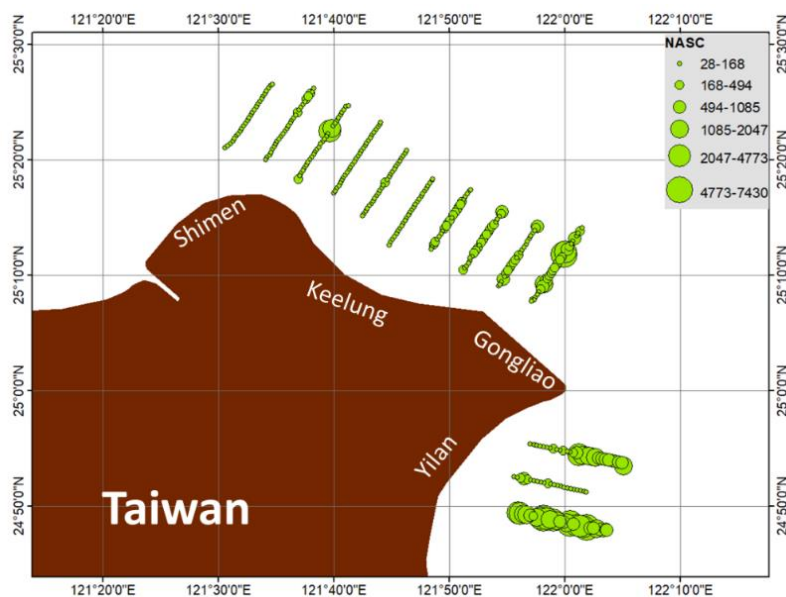
*Figure 2. Thematic map of NASC values in 500 m intervals. Circle size is proportional to the value of NASC*

Fish distributional characteristics: coastal line

Large and dense fish aggregations were observed based on the echogram curtain and the horizontal NASC map of the coastal line (*Fig. 3*). In particular, high NASC was found below 25°N (marked arrow in the *Fig. 3*). Acoustic data were collected at night so that a number of fish aggregations were inspected (*Fig. 3A*). Note that the long thin layers in black on the echogram curtain were echoes of second bottom signal which were processed as no-data. High NASC values were observed around off Gongliao and Yilan (25°10'N−25°50'N, *Fig. 3B*). The peak of NASC in vertical was at 70 m depth. NASC values gradually increased from water surface to 70 m and decreased as water depth became deeper (*Fig. 3C*).
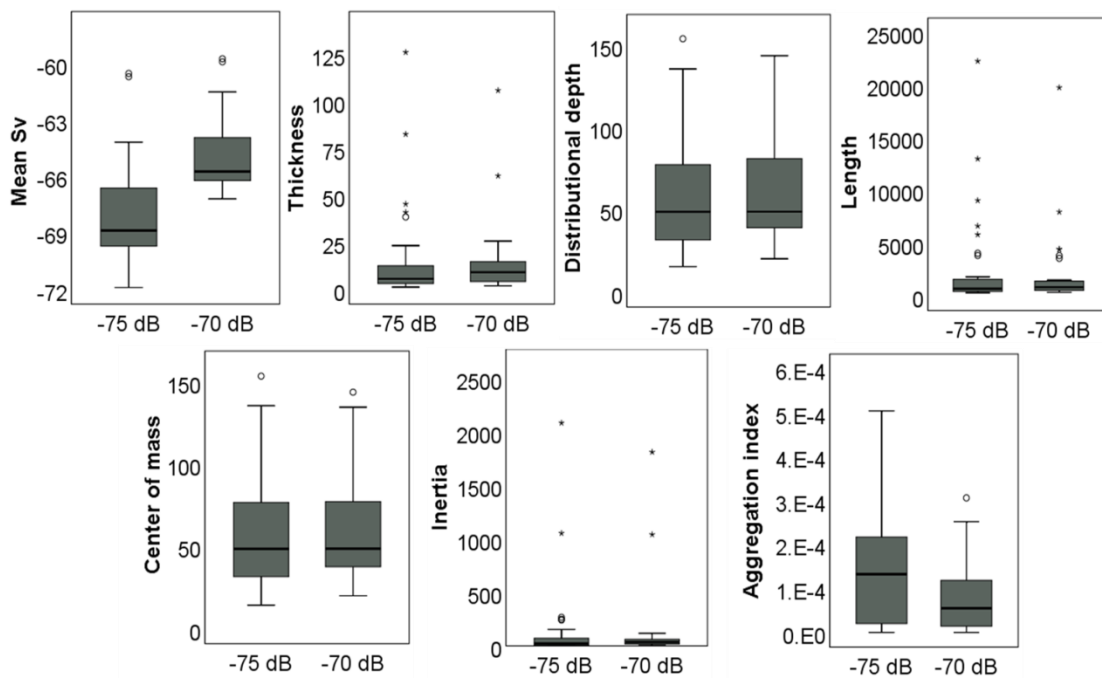
Metrics of fish distributional characteristics on the coastal line is graphed using boxplots and is presented in *Fig. 4*. Between two thresholds, mean S_V and aggregation index seemed to be different. Applying −70 dB of threshold, averaged mean S_V was −64.9 dB, mean thickness was 15.4 m, mean distributional depth was 65.1 m, mean length was 2201.2 m, mean center of mass was 64.9 m, mean inertia was 143.4 m^2, and mean aggregation index was 8E-05 m^{-1}. By using −75 dB of threshold, averaged mean S_V was −68.2 dB, mean thickness was 14.6 m, mean distributional depth was 60.2 m, mean length was 2312.7 m, mean center of mass was 59.8 m, mean inertia was 129.1 m^2, and mean aggregation index was 1.4E-03 m^{-1}. Seventy-five percentage of fish aggregation was distributed below 85 m, their thickness was smaller than 16 m, and their length was shorter than 1542 m. Half of fish aggregation had 32−79 m of the center of mass, 6−70 m^2 of inertial, and 1E-05−2.1E-04 m^{-1} of aggregation index. All fish distributional

characteristics between two threshold values had no significant difference except for Sv (Mann–Whitney, P=0.00, n=65). This means that a study on the distributional characteristics of hairtail can use either −70 or −75 dB threshold value.
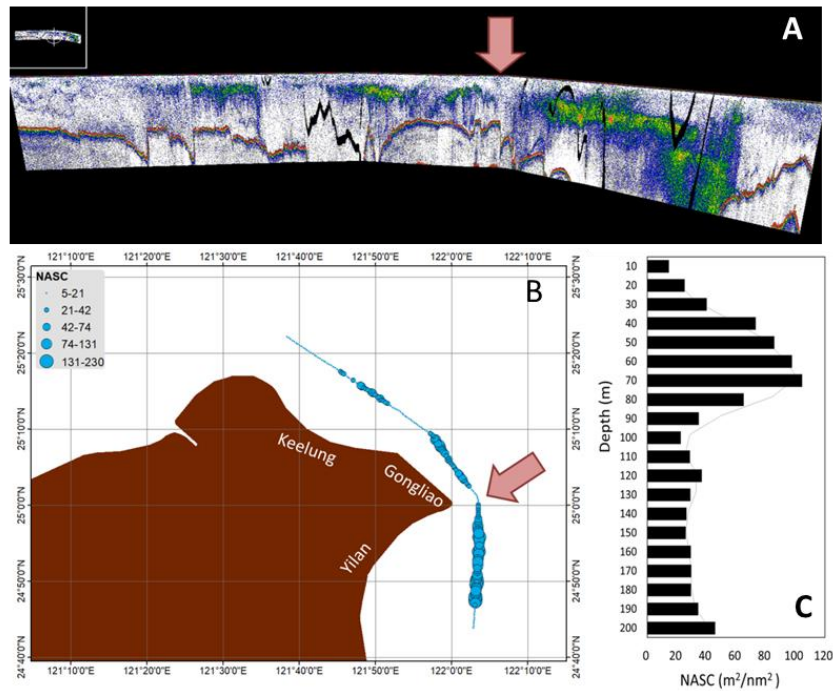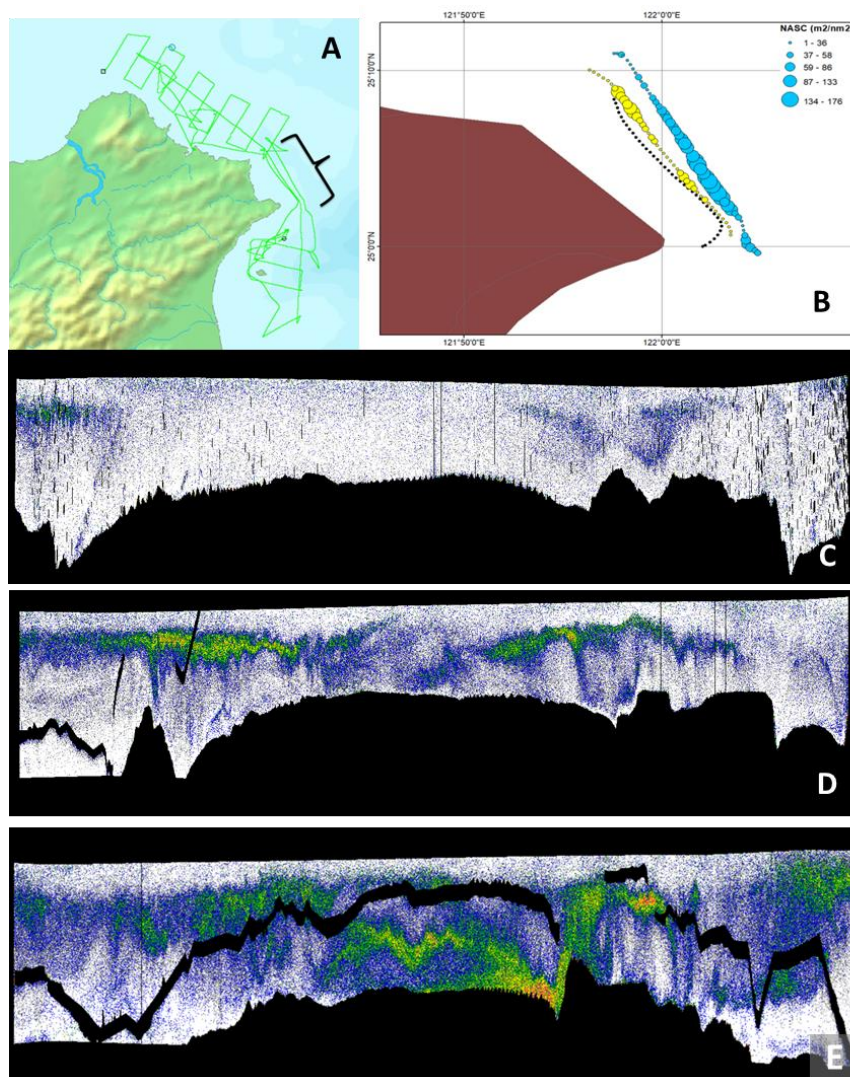

Figure 3. The echogram curtain A, the horizontal NASC map B, and vertical distribution of NASC C of the coastal line. Arrow means the change of vessel voyage direction and assists to compare A and B. The line C is moving averaged line


Figure 4. Metrics of fish distributional characteristics in coastal line using box plots

Fish distributional characteristics: three lines

The horizontal NASC map and the echogram curtains of three lines are shown in *Fig. 5*. The location of three lines was simply confirmed (*Fig. 5A*). Overall the highest NASC was observed on the outer line, the second highest NASC was on the middle line, and lowest NASC was on the inner line (*Fig. 5B*). Short and small black parts on the echogram curtain were removed noise marks and processed also as no-data (*Fig. 5C*). The long thin layers in black were echoes of the second bottom signal and processed as no-data (*Fig. 5D and 5E*). Each echogram curtain started top-left part of voyage track. Overall, strong echo signals occurred in outer and middle lines. The vertical distribution of NASC is shown in *Fig. 6*. The average NASC at outer line, middle line, and inner line were 63.1 m^2/nm^2, 30.1 m^2/nm^2, and 8.6 m^2/nm^2, respectively. Overall inner line had very low NASC throughout the water column. The middle line had 50 m peak of NASC while the outer line had 50, 90, and 140 m peaks although the highest peak occurred at 50 m.


***Figure 5.** Three lines on entire voyage line A, the horizontal NASC map of three lines B and the echogram curtains of inner line C, that of middle line D, and that of outline E*
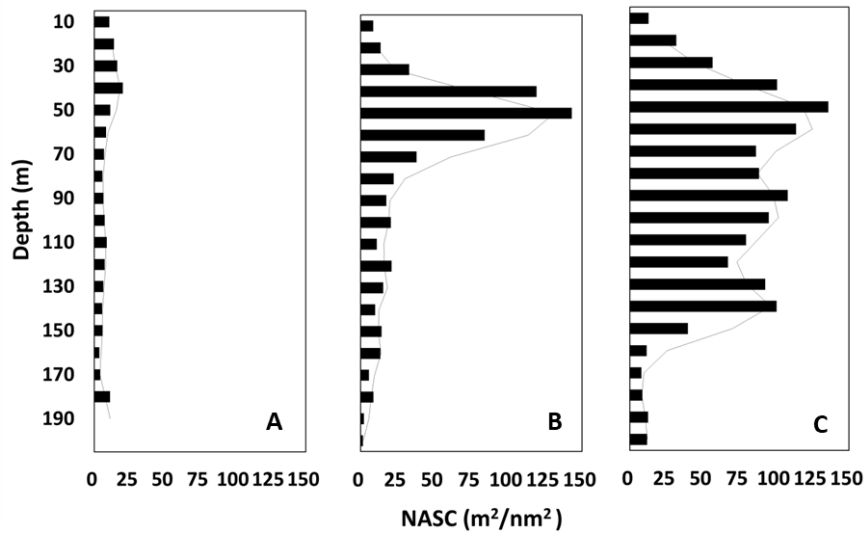
Figure 6. *Vertical distribution of three lines such as outer line A, middle line B, and inner line C*

Marine environmental property

Interpolated water temperature with NASC and interpolated salinity with that are shown in *Fig. 7*. The range of water temperature in 1–5 CTD stations was approximately 16–19°C up to 150 m deep, while that in 6–8 CTD stations was about 16–23°C. It was difficult to mention that rather high water temperature (20–23°C) would have influenced to high NASC. However, higher NASC on horizontal map (*Fig. 2*) was observed on the 6 and 8 CTD station. Slightly low salinity (34–34.2 psu) was observed near water surface in 1 to 3 CTD stations and up to 100 m deep at the 5th CTD station. In regard to the comparison between NASC and water temperature in vertical, high NASC values with 17–21°C in 50–100 m deep and 15–16°C in 160–200 m depth were observed in 6–8 stations. In 1–5 stations, high NASC with 18–19°C occurred in 50 m depth.
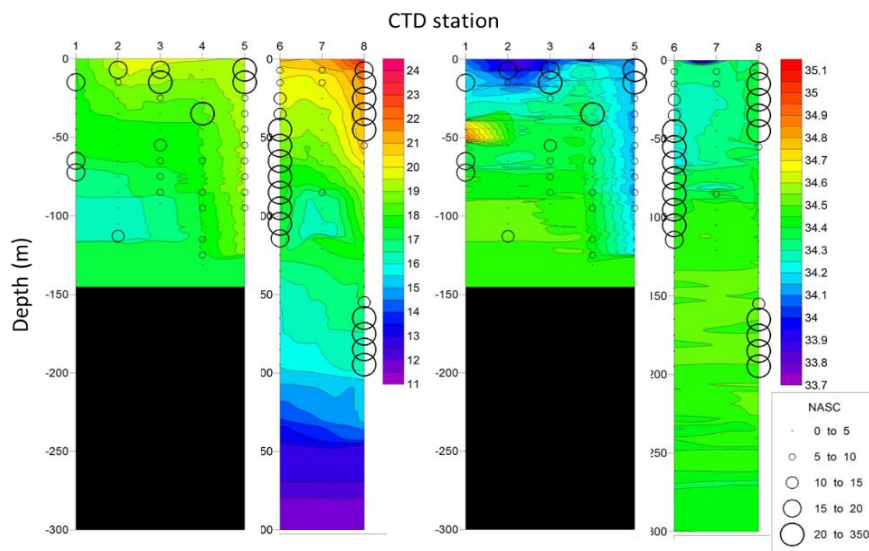
Figure 7. *Interpolated water temperature with NASC (left) and interpolated salinity with NASC (right)*

Discussion

Target strength of hairtail

TS of hairtail in this study was referred from Zhao (2006) which used juvenile hairtails whose anal lengths ranged from 60 to 120 mm with the mean of 90 mm, and measured *in situ* TS at night time. Tomiyasu et al. (2016) reported that hairtail was observed more than 60° swimming angle in 57.8% of experiment time (consecutive 3 days) with a peak of 77°. They also measured *ex situ* TS in response to swimming angle, and resulted in −47 dB of mean TS between 0–30° of body angle, −54.7 dB between 30–60°, −55.7 dB between 60–90°. It is well known that hairtail feed actively at night time. The foraging behavior causes great diverse swimming angles of hairtail, leading to various TS values. In consideration with these aspects, TS in this study would have not been accurate, although there are not many available and reliable TS for the species. For hairtail resource management, acoustic survey in day time is reliable since their movements and foraging activities at night are dynamic. For accurate biomass estimation of hairtail, reliable TS from hairtail aggregations during a daytime acoustic survey should be obtained although it is not easy to collect those data.

Spatial distribution of hairtail

Hairtail spawn almost year around with two dominant spawning periods such as autumn (November–December) and spring (March–April) in the East China Sea. They ordinarily spawn pelagic eggs in inshore areas and their larvae move to nearshore water. They maturate at age 1 and can live until age 9 in the East China Sea. In particular, hail, in the coastal area off Zhejiang Province of China, undergo seasonal migration from nearshore water to offshore water in the depth around 60–100 m for overwintering. Namely, they move back and forth between nearshore water for spawning and offshore water for overwintering (Ye and Rosenberg, 1991; Shih et al., 2011; Sun et al., 2020). Overall in this study, there was not clear observation that NASC of hairtail in nearshore water was higher than that in offshore water (*Figs. 2 and 5*). However, it is well known that Guisan Island, which is located very close to inshore, is a hotspot for hairtail spawning area. Average total length of hairtail from two different biological samplings in this study was 703.4 mm which was adult. It could be assumed that high NASC distribution in 10, 11, and 13 transect lines around Guisan Island indicated dense spawning hairtail aggregations. On the basis of knowledge on spatial distributional characteristics of hairtail, a design for next acoustic survey such as length, interval, and location of transect line and so forth can be improved. In addition, coastal water is through activities on land that increase delivery of nutrients to the sea. The consequence of food availability for population dynamics and migration of fish have an effect on their growth and a better chance to avoid from predators (Bailey and Houde, 1989).

Hairtail resource management

Global hairtail harvests are 1,217,280 tons in 2017 and annually around 1,250,000 tons between 2013 and 2017 (FAO, 2017). In particular, the total catch of this species in 2019 was 43,479 tons in Republic of Korea (Fisheries statistics, 2020) and that in 2018 was 16,058 tons in Taiwan. In the East China Sea, the hairtail is one of the most important species in commercial and ecological. They are caught primarily by demersal trawl and trivially by set net, gill net and longline. In Taiwan, because hairtail fishery is not under the total allowable catch system, it does not produce long-term scientific data which are

significant to its resource management and relevant policy formation. As a result, this fishery is exposed a danger of an overfishing issue. The average body length from catch has gradually been decreased, and the species has been matured at relatively younger age due to the heavy fishing pressure (Du et al., 1988; Ji et al., 2019). Accordingly, knowledge on the population and distribution of hairtail is beneficial to facilitate its sustainable exploitation. It is of interest to fisheries scientists and resource managers to understand the status of hairtail stock as accurate as possible in the East China Sea, especially water around Taiwan. In this study, three interpretation scenarios of hailtail allocation in total backscatter were not the best. However, the utilization of acoustic system in extensive areas can expeditiously define fish stocks to estimate the fish biomass efficiently (Simmonds and MacLennan, 2005). Thus, an integrated acoustic trawl survey along with sufficient number of trawls would be a promising tool for aiding useful and feasible measures of hairtail resource. In consideration with results from this study, an integrated acoustic trawl survey will be performed in every month from September, 2020 to March 2021. The transect lines will be divided in northwestern part of Keelung (25.25°N–25.20°N and 121.50°E–121.90°E), region around Guisan Island (24.75°N–25.00°N and 121.75°E–122.15°E), and region off Gongliao (25.15°N–25.3°N and 122.15°E–122.35°E). Sufficient number of trawls will be conducted along with pole and line fishing as the secondary option.

Environmental influence to hairtail

The continental shelf of the South and East China Seas is one of the greatest habitats in the surrounding waters of the Western North Pacific. In the northeastern waters of Taiwan, the Kuroshio Current runs nearby the 200 m isobaths mainly during winter season, and away from it during summer season. On the other hand, the China Coastal Current, which flows southward from Bohai sea to the Taiwan Strait and into the South China Sea, strongly interacted with Kuroshio Current in winter. The intensity of Kuroshio Current and China Coastal Current is a predominant element that leads to marine environmental changes in this study area (Lu and Lee, 2014). In consideration with this aspect, the water temperature in 6–8 CTD stations, in which was strongly affected by the Kuroshio Current, was higher than that in 1–5 stations. Water temperature affects growth, feeding, and breeding of fish, and alters the aptness of marine habitats. Accordingly, it brings in modification in the abundance and distribution of fish species (Wood and McDonald, 2008). Environmental variables, for example water temperature, salinity, and chlorophyll et cetera, affect the timing and duration of the fish reproduction, as well as the abundance and distribution of their preys. The interactions among the variables are complicated and difficult to be isolated (Seo and Kim, 1999; Liu and Gan, 2012). Future studies need to assess how environmental elements may attribute feasible interactions between spatial distribution and preys of hairtail, in particular spawning adult. In addition, the trends of variation in catch number and population of hairtail might be due to fluctuations in the intensities of the Kuroshio Current and China Coastal Current. The relationship between two currrents and hairtail abundance would be an interesting topic for future studies.

Biological sampling gear

All fishing gears are, to the extent, selective and catch individuals in species, body length, and age composition that deviate from their true composition in nature (Wileman et al., 1996; Suuronen, 2005). Humphries et al. (2019) compared two fishing gear types:

spearguns and handlines, and reported that both gears caught high diversity of fish, but spearguns removed more species and handline catches had a wider range of fish sizes than Spearguns. Food and Agriculture Organization (FAO) reported general overview on fishing gear selectivity (Thompson and Yami, 1983). For example, by using 6 bottom drag nets (Bobbin trawl, Pair Trawl, Light trawl, Scottish seine, Danish seine, and Nephrops trawl), the percentages of different species caught from 6 drag nets varied considerably. It indicates that different types of trawls are selective in different ways although their performance also differed. Pole and line fishing is one of extremely species selective gears, and in general it does not take any other fishes except for the intended species. On the other hand, demersal fish trawl is less selective gear although the mesh size is a key element for fishing species selectivity. For acoustic survey for estimating hairtail biomass, a less selective fishing gear such as trawl would be appropriate. In this study, only one trawl was conducted yet pole and line fishing confirmed the existence of hailtail in the study area. In fact, wind and waves in the northern off Taiwan were very bad in December 2020 so that it was very difficult to carry out a trawl. Also, it was the first time to conduct a trawl in northern water using the RV Fisheries Research 2 for a short amount of preparation. To improve the accuracy of the hairtail resource assessment, a multi-species selective fishing gear such as trawl with an appropriate number of trawl stations will be adapted in next survey.

Conclusion

To estimate the biomass and spatial distributional characteristics of hairtail, an acoustic transect line survey, in concurrent with 7 pole and line fishing and 1 trawl sampling, was conducted from 10 to 17 Dec 2019 in the northern sea of Taiwan. The hairtail biomass, under three scenarios such as low, medium, and high of acoustic backscatter allocation, were to be 5286 (30%), 7048 (40%), and 8810 tons (50%), respectively. For horizontal distribution of hairtail, east part off Keelung city presented rather high NASC than in west part, in particular waters off Yilan county (below 24°50'N) had the highest NASC. Using acoustic data from a long coastal line and three lines at a very similar location, 75% of fish aggregation occurred below 85 m, their thickness was smaller than 16 m, and their length was shorter than 1542 m. The average NASC at outer line, middle line, and inner line were 63.1 m^2/nm^2, 30.1 m^2/nm^2, and 8.6 m^2/nm^2. The statistical analysis revealed significant difference between all three line groups. Lastly, high NASC occurred in the range of 15–21°C in 50–200 m depth. The result of this study will support in designing an integrated acoustic trawl survey next year.

Data availability. All data sets used in this paper are available upon request with a reasonable reason from the first author (mk@gnu.ac.kr).

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