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Research Article

Age and growth changes and population dynamics of the black pomfret (*Parastromateus niger)* and the frigate tuna (*Auxis thazard thazard),* in the Taiwan Strait

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ABSTRACT. The age and growth and population dynamics of the black pomfret, *Parastromateus niger* and the frigate tuna, *Auxis thazard thazard* were studied from specimens collected monthly in the Taiwan Strait from April 2005 to March 2006. With five age groups of each, the dominant black pomfret was one year, while frigate tuna was two years. The total mortality coefficient (*Z*) and the fishing mortality (*F*) of the black pomfret were at high levels, the exploitation ratio (*E*) was over 0.5, and the number of captured juvenile fishes showed that the stock of black pomfret in this area was overexploited and improper fishing gear was utilized. Compared with previous studies, the maximum and mean fork length, body weight and age of the two fishes declined gradually, the populations were younger in age and smaller in size. The growth coefficient *k* increased and age at the inflexion point of weight t_r was younger than before. The smaller change of the fork length at first maturity of the two fishes has indicated a more vulnerable fishery ecosystem in this area. Therefore, in addition to the traditional fishery management approach, such as taking the minimum length into consideration, ecosystem approach to fisheries management (EAF) should be taken to improve the practical fishing management, including conserving the small pelagic fishery population in order to achieve the sustainable fishing of the stocks.

Keywords: *Parastromateus niger*, *Auxis thazard thazard*, age, growth, population dynamics, management, Taiwan Strait, China.

Cambios en la edad y el crecimiento y dinámica poblacional de la palometa negra (*Parastromateus niger)* y del atún fragata (*Auxis thazard thazard),* en el estrecho de Taiwán

RESUMEN. La edad y crecimiento de la palometa negra, *Parastromateus niger* y del atún fragata o melva, *Auxis thazard thazard* se estudiaron a partir de especímenes capturados mensualmente en el estrecho de Taiwan, entre abril 2005 y marzo 2006. Se determinaron cinco grupos de edad, siendo dominante en la palometa negra los ejemplares de un año, mientras que en el atún fragata los de dos años. El coeficiente de mortalidad total (*Z)* y la mortalidad por pesca (*F*) de la palometa negra se encontraron en niveles altos. La tasa de explotación *E* resultó sobre 0,5 y el número de peces juveniles capturados demuestra que la población está sobreexplotada en la región y los equipos de pesca utilizados resultan inadecuados. En comparación con estudios previos, la longitud horquilla máxima y media, el peso corporal y la edad en ambas especies ha disminuido en forma gradual, presentando las poblaciones peces de menor edad y tamaño. El coeficiente de crecimiento *k* aumentó y la edad en el punto de inflexión en peso t_r se obtuvo en ejemplares más jóvenes que en años previos. El pequeño cambio de la longitud horquilla determinado en la primer madurez en las dos especies indica que en esta zona, el ecosistema pesquero se encuentra más vulnerable. Por eso, además del enfoque tradicional en la gestión de la pesca, como la adopción de una longitud mínima, se requiere adoptar el enfoque ecosistémico a la ordenación de la pesca (EEP) para mejorar la conservación de la población de pequeños pelágicos y lograr así el desarrollo sostenible de los recursos pesqueros.

Palabras claves: *Parastromateus niger, Auxi thazard thazard*, edad, crecimiento, dinámica poblacional, manejo pesquero, Estrecho de Taiwán, China.

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INTRODUCTION

The black pomfret, *Parastromateus niger* (Bloch, 1795), is a small pelagic fish that inhabit the shallower inshore waters of the Indian Ocean to the western Pacific Ocean, it is distributed off East Africa to southern Japan and Australia (Liu, 2008). The frigate tuna, *Auxis thazard thazard* (Lacepède, 1800), is a small pelagic tuna-like member of the family Scombridae which includes tunas, mackerels and bonitos. It is a highly migratory species with a worldwide distribution throughout all tropical and subtropical seas (Liu, 2008). In China, the black pomfret and frigate tuna are distributed in the East China Sea and South China Sea, they are more abundant in the Taiwan Strait, and are important for the lighting purse seine fishery in Taiwan, Fujian and Guangdong Province (Lu & Yan, 1985; Lu *et al.*, 1991). Studies on their age and growth and population dynamics are very important for analyzing the changing trend in fish populations and evaluating the level of fish being exploited.

The age and growth determination, biology and fishery of the *P. niger* have been studied in China (Lu & Yan, 1985; Lu *et al.*, 1986; Yang *et al.*, 2009), Philippines (Hernando, 1981), India (Khan *et al.*, 1992) and Malaysia (Maran *et al*., 2009), and a few studies have reported on *A. thazard* in China (Lu *et al.*, 1991; Lu *et al.*, 1992; Zhang *et al.*, 2006; Yan *et al.*, 2009), India (Jones, 1957; Muthiah, 1985; Jude *et al.*, 2002), Guinea (Voegborlo *et al.*, 2007), USA (Uchida, 1981) and Australia (Hoese *et al.*, 2006). However, little information on the age and growth characteristics and population dynamics of these species is available, accordingly, adequate fishery assessment and management of the two fishes in the Taiwan Strait are impossible. This paper studies the age and growth characteristics of black pomfret and frigate tuna in the Taiwan Strait, and discusses the changes in population dynamics by comparison with previous studies.

MATERIALS AND METHODS

Sampling area

The black pomfret and frigate tuna were sampled by lighting purse seine monthly in the Taiwan Strait from April 2005 to March 2006 (Fig. 1). The Taiwan Strait is subtropical and it is an important interface between the East China Sea and the South China Sea, which is impacted by a branch of the Kuroshio Current and a South China Sea Warm Water current, the appropriate water temperature and salinity make this area a good habitat for the black pomfret and frigate tuna.

Age determination

The age of black pomfret was determined by their scales, as each scale contains concentric growth band pairs, including translucent and opaque bands. The scales were observed under microscope directly after rinsed and dried. While the age of frigate tuna was determined by their vertebrae, and the 4-5th vertebrae had the same band pair counts as those located in other locations and had the largest and exhibited sizes, these vertebrae were used for age determination in this study. Vertebrae were rinsed in 1% (winter) or 2% (summer) KOH for 1 day to remove connective tissue, washed in running water for 24 h, and then rinsed in glycerol for one day. A narrow band and a broad band appeared alternately on the vertebra surface. Radius of each centrum was measured to be 0.1 mm. The growth band pairs were examined under a microscope (60x). Growth band pairs were counted and measured without prior knowledge of the sex and length of the specimen. Counts were accepted only if both counts by two readers were in agreement. The distance from the focus to the outer margin of the translucent band of growth band pairs and the scale/vertebrae radius were measured as a straight line from the focus to the edge of the scale/vertebrae.

Biological parameters

The fork length (*FL*, in mm) and body weight (*W*, in g) of all the specimens were measured following the Specifications for Oceanographic Survey (Part 6: Marine Biological Survey, GB/T 12763.6-1991).

The mean values of gonadosomatic index (*GSI*) were used for the gonadal maturity analysis and first mature fork length determination of the two fishes.

$$GSI = \frac{W_g}{W_p} \times 100$$

where W_g is the gonad weight (g), W_p is the pure body weight (g), that is body weight without viscera weight.

The relationship between the fork length and the scale radius (*R*) was estimated by linear regression

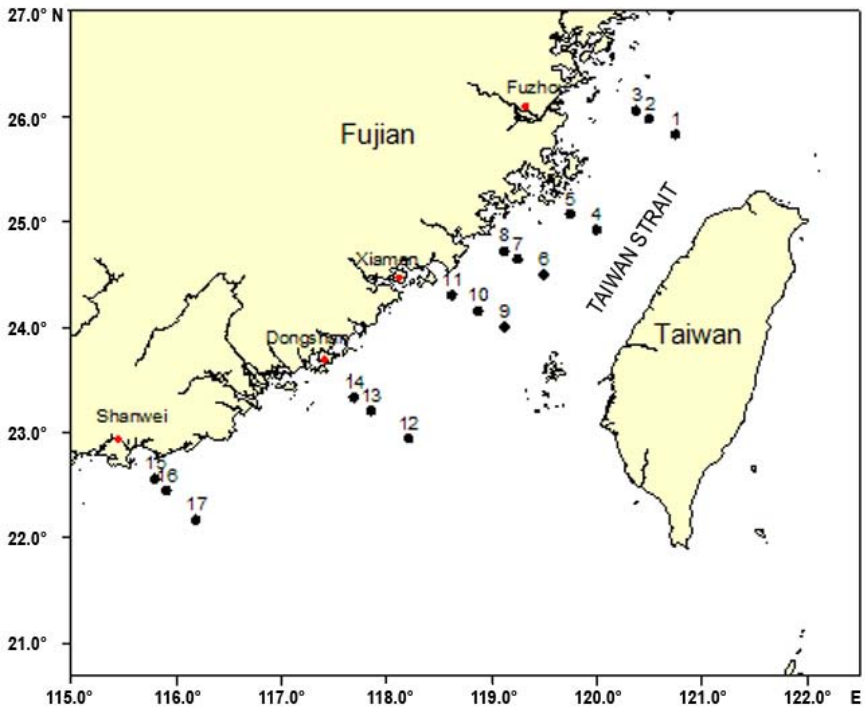

Figure 1. Survey stations (1-17) of black pomfret and frigate tuna in the Taiwan Strait.

Figura 1. Estaciones de muestreo (1-17) de palometa negra y atún fragata, en el estrecho de Taiwán.

analysis. The length-weight relationship was determined by the following allometric equation (Sparre & Venema, 1992):

$$TW = a \times FL^b \quad (1)$$

where TW is the total body weight (g), FL is the fork length (mm), a and b are the constants.

Growth was expressed in terms of the following equations (von Bertalanffy, 1938):

$$L_t = L_\infty (1 - e^{-k(t-t_0)}) \quad (2)$$

$$TW_t = W_\infty (1 - e^{-k(t-t_0)})^b \quad (3)$$

where L_t and W_t are the fork length and body weight at age t, L_∞ and W_∞ are the asymptotic fork length and body weight, k is the growth coefficient, t is the age (year from birth), and t_0 is the theoretical age when the specimen was at zero fork length.

The surviving ratio S was estimated using the equation relating to age distribution data for species (Robson & Chapman, 1961), then the total mortality coefficient Z was calculated though the following equation (Richer, 1975):

$$S = e^{-Z} \quad (4)$$

The natural mortality M for each species was estimated using empirical equation relating M to L_∞, k and the mean water temperature (Pauly, 1980):

$$\ln M = -0.0066 - 0.279 \ln L_\infty + 0.6543 \ln k + 0.4634 \ln T \quad (5)$$

where the mean temperature (T) of demersal water in southern Taiwan Straight is 23.466ºC.

The fishing mortality, F, was obtained by subtracting M from Z.

The exploitation ratio, $E = Z/F$. The parameter E expressed the proportion of a given cohort/population that ultimately dies due to fishing under an existing exploitation pressure (Beverton & Holt, 1966).

The minimum weight-limit was estimated using equation relating W_R to E and mean fishery landing weight ($\overline{W}$) (Allen, 1953):

$$W_R = E\,\overline{W} \quad (6)$$

Then, the minimum length-limit (L_R) can be calculated though the allometric equation stated above (Sparre & Venema, 1992).

RESULTS

TW-FL relationships

The total of 587 and 584 individuals were collected for black pomfret and frigate tuna, respectively. All the samples were measured in fork length and body weight. (Table 1). Both black pomfret and frigate tuna

consisted of five year groups, the dominant group of black pomfret was one year, while frigate tuna was two years. The relationship between total weight and fork length is described as follows:

black pomfret:

$$TW = 4.4416\times10^{-5}\,FL^{2.9811}$$

(n = 587, r = 0.9433, F = 4724.2 > $F_{500,0.01}$ = 6.69)

frigate tuna:

$$TW = 0.1815\times10^{-5}\,FL^{3.3899}$$

(n = 584, r = 0.9689, F = 6991.0 > $F_{1000,0.01}$ = 6.66)

The analysis showed that the exponent b of black pomfret was close to 3.0, which indicated that its growth was isometric, while b of frigate tuna was a little bigger than 3.0, though it was in the range 2.5-3.5.

Von Bertalanffy equations

The von Bertalanffy growth equation was fitted to all back-calculated *FL*s:

black pomfret: $L_t = 341.17\times(1-e^{-0.3157(t+1.7045)})$

$$TW_t = 1405.78\times(1-e^{-0.3157(t+1.7045)})^{2.9611}$$

frigate tuna: $L_t = 481.78\times(1-e^{-0.5230(t+0.3319)})$

$$TW_t = 2256.66 \text{ x } (1-e^{-0.5230(t+0.3319)})^{3.3899}$$

The fork length and body weight growth rate curves of the two fishes could be analyzed by calculating the first derivative of von Bertalanffy growth equation. The fork length growth rates are curves decreasing with age until the curve approaches zero, while the body weight growth rates are parabolas first increasing with age until the age reaches t_r (the age at the inflexion point of body weight), then decreasing with age (Fig. 2). The t_r of black pomfret and frigate tuna are 1.67 and 2.00 years, respectively (Figs. 2 and 3).

The fork length and body weight acceleration curves of the two fishes could be analyzed by calculating the second derivative of growth functions. The body weight acceleration is positive before the age reaches t_r. The body weight growth rate reaches the maximum value when the age reaches t_r. The body weight acceleration is negative after the age has reached the t_r when the body weight growth rate decreases (Fig. 3).

Mortality characteristics

The fishing mortality F of the black pomfret was much higher than that of the frigate tuna, and the exploitation ratio E of the black pomfret was more

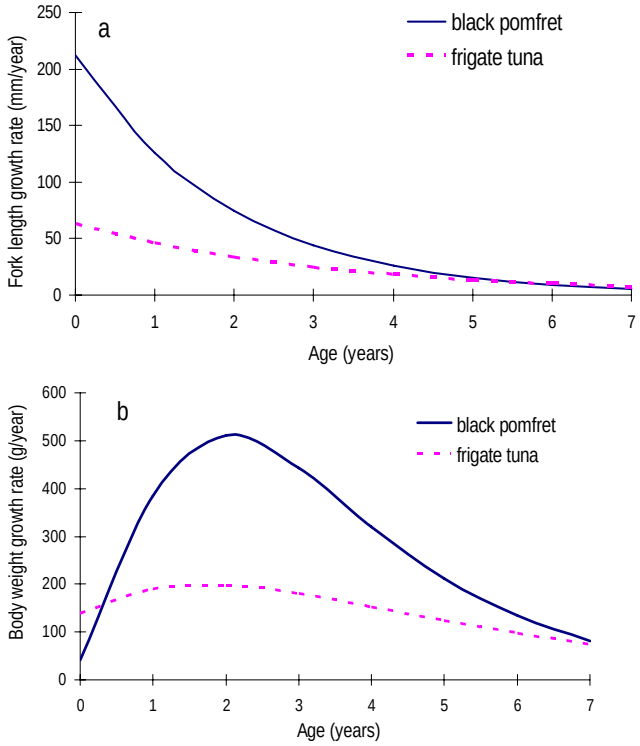

Figure 2. a) Fork length growth rate, and b) body weight growth rate of black pomfret and frigate tuna in the Taiwan Strait.

Figura 2. a) Tasa de crecimiento en longitud horquilla, y b) tasa de crecimiento en el peso corporal en la palometa negra y el atún fragata, en el estrecho de Taiwán.

than 0.5, indicating that the black pomfret was exploited in the Taiwan Strait. Based on E, of the two fishes, the minimum length-limit of black pomfret and frigate tuna were calculated as 158.91 mm and 226.82 mm, respectively (Table 2).

The gonadial maturity and minimum mature fork length of the two fishes were also analyzed (Table 2). About 16.87% (black pomfret) and 19.65% (frigate tuna) landed from the lighting purse seine fisheries were lower than the minimum mature fork length, indicating that a large number of juvenile and young fishes died due to being caught.

DISCUSSION

Compared with the population structure of the black pomfret and the frigate tuna studied in the Taiwan Strait in the past years (Lu & Yan, 1985; Lu *et al.*, 1991), the maximum and mean fork length, body weight and age of the two fishes decreased, the populations were younger in age and smaller in size (Table 1). For example, compared to that of 1982-1984, the mean fork length, body weight and age of

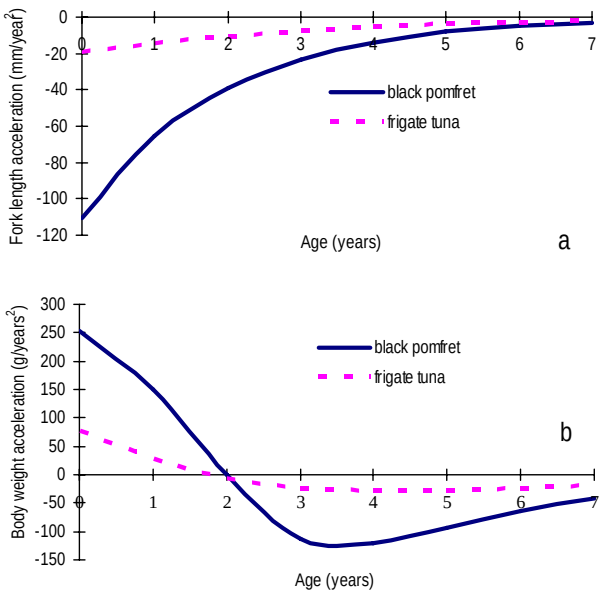

Figure 3. a) Fork length acceleration curves, and b) body weight acceleration curves of black pomfret and frigate tuna in the Taiwan Strait.

Figura 3. a) Curvas de aceleración respecto a la longitud horquilla, y b) curvas de aceleración del peso corporal, en la palometa negra y el atún fragata, en el estrecho de Taiwán.

frigate tuna have decreased from 349.0 mm, 662.9 g and 1.88 a to 321.5 mm, 622.3 g and 1.79 a respectively, indicating that the fisheries ecosystem has turned to be vulnerable.

The exploitation ratio *E* expressed the proportion of a given population that ultimately dies due to fishing under an existing exploitation pressure. Suitable *E* was related with natural mortality, fecundity and other factors, and different species have different suitable *E*. The suitable *E* was suggested to be between 0.308-0.500 or no more than 0.5, the balance of recruitment and catch would be disturbed if *E* was over 0.5 (Cushing, 1968; Gulland, 1971; Zhan, 2000). For black pomfret in the Taiwan Strait, *F* was at a high level, and *E* was over 0.5 (Table 2), and 16.87% of the catches were smaller than the minimum mature fork length, which indicated that the stock of black pomfret in this area was overexploited and the fishing gear was irrational.

The growth characteristics of the two fishes in the Taiwan Strait has also changed by comparison with previous studies (Lu & Yan, 1985; Lu *et al.*, 1986, 1991, 1992). The growth coefficient *k* increased, and the age at the inflexion point of weight (t_r) was younger than before (Table 2). The changes of the ecological characteristics were impacted by human disturbance, environmental changes and their biological characteristics, but the main factor was the overfishing (Luo *et al.*, 1993; Lu *et al.*, 1995). The overfishing of fish has taken much more of the recruitment, and resulted in significant declines of the population, especially the older members. This has moderated the feeding competition and made the younger ones grow faster.

Frigate tuna grows to almost 600 mm fork length and a weight of nearly 4,000 g, but they are more commonly 250-400 mm and 300-1,300 g in Australia (NSW, 2007), similar with that in the Taiwan Strait. The length at first maturity of frigate tuna in Thoothukkudi coast (southeast coast of India) was 328 mm and 308 mm for females and males respectively (Jude *et al.*, 2002), a little longer than that in the Taiwan Strait, which indicated that the frigate tuna in the Taiwan Strait and in the Thoothukkudi coast may be different populations due to geographic isolation, however, there is not much evidence to prove that, and further studies need to be carried out.

Black pomfret and frigate tuna in the Taiwan Strait are in the middle layer of the food web as the middle carnivores playing an important role in the food web of fishes in the Taiwan Strait (Zhang *et al.*, 1981). The whole marine ecosystem structure may be subjected to impacts if the ecological characteristics and population dynamics of black pomfret and frigate tuna deteriorates. So, the protection and management of the resources should be intensified. As many juvenile and young fishes were captured in this area, the first capture length should be implemented. Based on this study, the suggested minimum length-limit of black pomfret and frigate tuna are 158.91 mm and 226.82 mm respectively (Table 2).

The ecosystem approach to fisheries (EAF) assessment and management has led to global acceptance and awareness of the limitation of traditional fisheries management (FAO, 2008). EAF is a new concept in fisheries management, which emphasizes integrated fisheries management from the perspective of the whole marine ecosystem, and the implementation of EAF may improve the fisheries management in China (Zhang & Mu, 2006; Tang & Zou, 2009; Chu, 2010). The spawning season of the black pomfret in the Northern Taiwan Strait is earlier than that in the Southern Taiwan Strait: May-June, June-July and July-August in Northern, Middle and Southern Taiwan Strait, respectively. In addition, the juvenile and young fishes are broadly distributed in shallower inshore waters, most of the black pomfret in August to October are smaller than the minimum length-limit, and they were often fished by the stake nets and small fisher (Lu *et al.*, 1985). So, the spawning ground should be protected at the right time

Table 1. Changes in composition of fork length, body weight and age of black pomfret and frigate tuna in Taiwan Strait

Tabla 1. Cambios en la composición de la longitud horquilla, peso corporal y la edad de la palometa negra y el atún fragata, en el estrecho de Taiwán.

Species	Years	Fork length composition (mm)			Body weight composition (g)			Age composition (years)			Authors
		range	mean	dominant group	range	mean	dominant group	range	mean	dominant group	
Black pomfret	1981-1984	166-330	206.3	191-210	122-925	251.9	175-275	1-5	1.22	1	Lu & Yan (1985)
	2005-2006	143-305	189.3	181-200	110-797	231.7	151-250	0-5	1.06	1	Current study
Frigate tuna	1982-1984	201-469	349.0	361-390 and 281-300	109-2420	662.9	651-1150	0-5	1.88	2	Lu *et al.* (1991)
	2005-2006	198-456	321.5	341-380 and 261-280	88-2210	622.3	551-1000	0-5	1.79	2	Current study

Table 2. Changes in the biological parameters of the black pomfret and the frigate tuna in the Taiwan Strait. $L_{\infty,}$ the asymptotic fork length; *k*, the growth coefficient; t_0, the theoretical age when the specimen was at zero fork length; L_t, the fork length and body weight at age *t*; *Z*, the total mortality coefficient; *M*, the natural mortality; *F*, the fishing mortality; *E*, the exploitation ratio; L_R, minimum length-limit ; *MMFL*, the minimum mature fork length.

Tabla 2. Cambio en los parámetros biológicos de la palometa negra y el atún fragata en el Estrecho de Taiwán. $L_{\infty,}$ longitud horquilla asintótica; *k*, coeficiente de crecimiento; t_0, edad teórica cuando el espécimen tiene la longitud horquilla igual a 0; L_t, longitud horquilla y peso corporal a la edad *t*; *Z*, coeficiente de mortalidad total; *M*, mortalidad natural; *F*, mortalidad por pesca; *E*, tasa de explotación; L_R, mínimo longitud límite; *MMFL*, longitud mínima de madurez.

Species	Years	L_∞ (mm)	K (year^{-1})	t_0 (a)	t_r (a)	Z	M	F	E	L_R (mm)	*MMFL* (♀, mm)	*MMFL* (♂, mm)	Authors
Black pomfret	1981-1984	343.10	0.3050	-1.9000	1.78	1.73	0.72	1.01	0.59	-	195	184	Lu & Yan (1985)
	2005-2006	341.17	0.3157	-1.7045	1.67	1.82	0.74	1.09	0.60	158.91	191	181	Current study
Frigate tuna	1982-1984	484.44	0.5109	-0.3598	1.45	1.14	0.90	0.23	0.21	-	273	276	Lu *et al.* (1991)
	2005-2006	481.78	0.5230	-0.3319	2.00	1.31	0.91	0.40	0.31	226.82	269	271	Current study

- data not available.

of the year and the fishing gears and methods should be improved too.

Frigate tuna in Taiwan Strait is carnivorous, its trophic level is 3.3 as it feeds mainly on fishes like Bregmacerotidae and Clupeidae (trophic level: 2-3), and in a minor level on Macrura (trophic level: 1.8) (Zhang *et al.*, 1981). The small pelagic fishes occupy a large proportion in the diet. So, the whole fishery ecosystem, especially the small pelagic fishes should be protected first based on EAF. Meanwhile, there are many fish species that compete for food with frigate tuna, and many of them are non-economic species like *Echenis naucrata*. So it is necessary to increase the fishing intensity on the non-economic species and to reduce the feeding competitors of frigate tuna, a potential benefits for the sustainable use of frigate tuna stock.

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