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A Comparison of Catch Rates of C-Hooks and J-Hooks in the Hook-and-Line Tuna Fishery

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ABSTRACT

Harvesting oceanic tuna species has played a very important role in the social economic development, income, and livelihoods throughout the central provinces of Vietnam. The hook-and-line (handline) with artificial light using J-shape hooks (so-called J-hooks) is the primary fishing method used to catch the yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) in the South China Sea. However, this fishery has a challenge of incidental catch of sea turtles. This study investigated the catch comparisons of hook-and-line fishery using C-shape hooks (so-called C-hooks) versus conventional J-hooks in the purpose of reducing the incidental catch of sea turtles. Field experiments were conducted from February to May 2022 onboard the commercial fishing boat and showed that C-hooks caught the same amount of all species compared to the J-hooks. In addition, C-hooks caught larger yellowfin tuna than the J-hooks. Our results show that the use of C-hooks in hook-and-line fishery has the ecological and economic benefit in terms of endangered species protection and maintenance of catch rates of wanted species.

INTRODUCTION

Commercial harvesting of oceanic tuna is one of the most important marine fisheries and denotes a significant source of revenue for the Vietnam seafood industry **(Nguyen & Gao, 2010; Nguyen & Jolly, 2018)**. The oceanic tuna fishery in Vietnam started in 1992 under the JACA (Japan International Cooperation Agency) project, including modern technology transfer and provision of Japanese second hand fishing boats **(Duong, 2002; Nguyen *et al.*, 2013, 2022a)**. Initially, fishermen used longlines to catch the yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*), aboard offshore wooden fishing vessels with an overall length (LOA) ≥ 15m and equipped with inboard engines (≥ 90HP) **(Le *et al.*, 2008; Nguyen, 2011; Nguyen *et al.*, 2013)**. A longline ranged between 20 and 30km in length with 800 – 1,200 hooks connected to the longline, baited with frozen squid (*Sthenoteuthis oualaniensis*) or/and the yellowfin flyingfish (*Cypselurus poecilopterus*), and soaked overnight **(Nguyen, 2011)**. Recently, hook-and-line with powerful artificial light (surface light) fishing methods have received more attention due to higher catch rates and to date, few longliners are operating **(Tran, 2015; Nguyen *et al*., 2022a)**. Fishermen use different types and sizes of hooks based on their experiences and interests, with a majority of 14/0 J-hooks **(Tran, 2015; Do *et al*., 2019, VINATUNA, 2020)**. The three central coastal provinces, including Khanh Hoa, Phu Yen, and Binh Dinh, are the main contributors to total oceanic tuna landings and exports **(Long *et al*., 2008; Nguyen & Gao, 2010; Nguyen & Jolly, 2018)**. Annual landings were approximately 16,000 metric tonnes. Total export value increased from ~ USD $300 million in 2010 to USD $750 million in 2023 **(General Statistics Office, 2023; VASEP, 2024)**. The European Union, the United States of America (USA), and Japan are the key markets of Vietnamese oceanic tuna products, however, new markets such as China, Latin America, Israel, and other countries are also considered during the past years **(Nguyen & Jolly, 2018; VASEP, 2024)**. The main exports are sashimi (whole raw fish), frozen, and canned **(Nguyen, 2011; Nguyen & Jolly, 2018)**. Moreover, the main fishing ground of oceanic tuna hook-and-line fishery is in the offshore South China Sea. There are two periods of fishing seasons corresponding with the northeast monsoon (from October to March) and the southwest monsoon (from April to September) **(Nguyen, 2011)**. The number of operational days and the catch efficiency during the southwest monsoon season is typically greater than that in the northeast monsoon season due to many tropical storms **(Duong, 2002; Nguyen, 2011)**. In response to the fluctuation of the economic feasibility and resources, the number of oceanic tuna fishing boats varied between years and peaked at 3800 fishing boats in 2005 and declined to 2100 active boats in 2023 **(Nguyen *et al*., 2013; General Statistics Office, 2024)**.

There is considerable concern over the ecological effect of interactions between sea turtles and pelagic longline fisheries, which extends throughout tropical and temperate regions of the world's oceans **(Gilman & Huang, 2017)**. All seven sea turtle species living in the oceans are listed under threatened or endangered categories **(IUCN, 2019)**, and international and national trade and commercial capture of these species is illegal and prohibited **(CITES, 2021)**. As a highly migratory species, combined with a high density of longlines operating throughout the oceans, an estimate of more than 50,000 leatherbacks (*Dermochelys coriacea*) and 200,000 loggerheads (*Caretta caretta*) were incidentally captured by longline fisheries globally **(FAO, 2001; Lewison *et al*., 2004; Swimmer & Brill, 2006)**. Finding methods to mitigate the bycatch of sea turtles and to maintain the capture of target species is a worthwhile approach as it can contribute to the ecological conservation goal. Past technical and management measures included restricted annual fishing efforts, limited soak time, mandatory fishing depth, and adjusting fishing time, shifting fishing technologies **(Swimmer & Brill, 2006; Gilman & Huang, 2017)**.

The artificial light, i.e. lightsticks plays a primary role in attracting target species for the pelagic longline fisheries catching swordfish and tuna, but it also produces a significant source of stimulus for unwanted species including sea turtles **(Nguyen & Winger, 2019**). When Vietnamese oceanic tuna longlines shifted to hook-and-lines, the fishing boats were powered with as much as 50kW of above-water light **(Tran, 2014)** to lure tunas to feed on prey (e.g., squid) which are themselves attracted by the light, resulting in higher catch rates. This light source is however identified as a potential factor to attract turtles and to interact with fishing hooks, and incidentally caught as bycatch. Although how much sea turtles are affected by artificial light fishing methods is not known, a number of studies found that turtles were attracted to light, resulting in vulnerable to incidental capture **(Wang *et al*., 2007; Gless *et al*., 2008)**. In addition, hook-and-lines capture fewer sea turtles than longlines, because only eight hooks are used during the fishing process compared to thousands of hooks for a longline, however, catch rates of sea turtles in the Vietnamese oceanic tuna hook-and-line fisheries are considerable **(VINATUNA, 2020; Nguyen *et al*., 2022a)**.

As the international regulations, all sea turtle species are protected by the Vietnamese Law of Fisheries **(Ngan, 2017)**. However, they are incidentally caught by different fishing gear such as trawl, gillnet, and others **(Do *et al*., 2019)**. To our knowledge, there is a lack of systematic information on sea turtle capture in the Vietnamese oceanic tuna longlines and hook-and-line fisheries. The only piece of information came from the studies of **Vu and Nguyen (2011)**, **Do *et al*. (2019)** and **VINATUNA (2020)** during the survey of catch composition of the Vietnamese tuna fisheries. Although fishermen usually release incidental catch of sea turtles, they often cut off the fishing line with a hook in the mouth to let the turtle swim away because it is faster or the hook is deep in the throat and is difficult to remove **(VINATUNA, 2020)**. Post-release mortality is likely high among sea turtles caught by longlines using JT-hooks **(Chaloupka *et al*., 2004; Watson *et al*., 2005; Carruthers *et al*., 2009; Swimmer *et al*., 2014)**. Naturally excluding the unwanted species from the catch is the best ecological approach to protect and conserve a healthy ecosystem and minimize any negative effects on endangered and protected species **(Gilman & Huang, 2017)**. Substantial studies have shown that the C-hook can reduce the bycatch of sea turtles in longline fisheries and can maintain targeted species **(Kerstetter & Graves, 2006; Sales *et al*., 2010; Pacheco *et al*., 2011; Rudershausen *et al*., 2012; Huang *et al*., 2016; Burns & Burns, 2019)**. It appears that C-hooks have promise for reducing the mortality of sea turtles, but this potential has not been well quantified for Vietnamese hook-and-line fishery. In addition, to be used commercially, the new hook type must be demonstrated in the field condition to have similar catch efficiency as the J-hooks to maintain the profitability of the fisheries. Building on this purpose, in this study, we compared the catch efficiency of wanted species between C-hooks and J-hooks used in the Vietnamese hook-and-line fisheries catching oceanic tuna species in the South China Sea.

MATERIALS AND METHODS

The sea trials were conducted in the South China Sea onboard the fishing boat *KH 96281TS* from February to May 2022 (Fig. 1). The boat was equipped with a total of 22 kW metal halide and fluorescent tube lamps to attract tuna. Hook-and-line was used to catch tuna as same as the commercial fishing practice (Fig. 2). There were four fishing rods equally placed in the port and starboard side (Fig. 2). In each fishing rod, there were two branch hooked lines at 60 and 80m depth. We consistently fished with C-hooks in the stern and J-hooks in the bow during the night and switched to alternating stern and bow of the boat every night to reduce any potential experimental bias. Live squid (*Sthenoteuthis oualaniensis*) that were freshly caught at sea by fishermen were used as bait. Squids were hooked closely in the stabilizing fin to stay alive for better attraction.

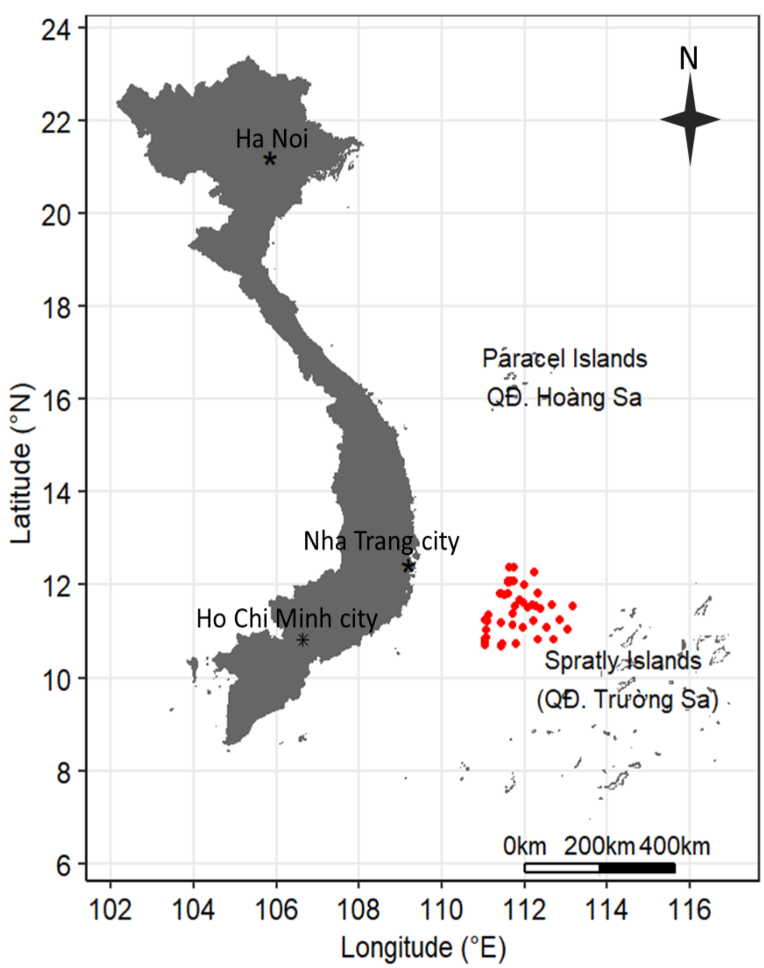
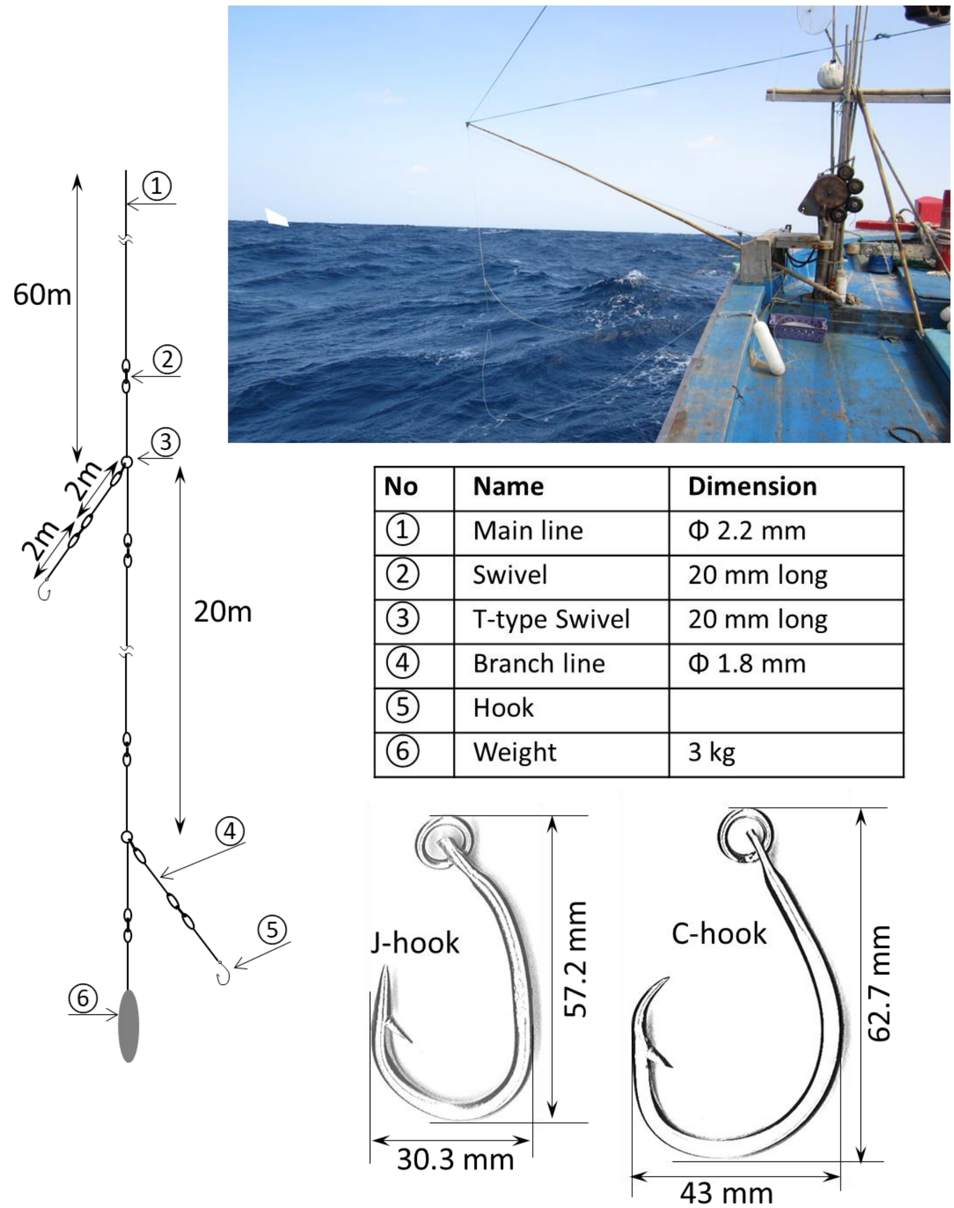


Fig. 1. Map of the study site located to the East of Nha Trang City. Each red dot represents a fishing night. There were several same fishing positions

The *KH 96281TS* departed from the Ho Ro port, Nha Trang city (Fig. 1) and arrived at the fishing ground in approximately two days. Fishing operations started at 6:00pm when the sea anchor was placed, and the fishing lamps were turned on to lure fish (perhaps the lights likely attracted tuna's prey which are attracted by the light) **(Nguyen & Winger, 2019)**. We regularly checked the bait every 30min to ensure that the bait was available and worked properly. When a fish was hooked, all the crew helped to retrieve the fishing line manually. The retrieving process took place very fast between 2 and 4 minutes depending on how the fish was struggling. Fish were immediately killed using a metal rope to damage the brain in order to maintain high-quality meat. Viscera and gills were removed, and fish were then chilled for 30 minutes in a plastic tank using ice water before handling it in the fish tank. Fishing operation was undertaken throughout the night-time period, until the daylight of the following day. The vessel was drifting approximately 5 nautical miles each night.

For each operation, all catches were sorted according to the species level and the number was recorded in the survey sheets. As the primary target species, tunas were measured the total length to the nearest cm and weighed in kg. Other trip information such as date, time, and position was also noted.

Non-parametric Mann-Whitney U-Test was used to compare the catch per unit effort (CPUE) between C-hocks and J-hooks, where the CPUE was the total number of fish caught per rod per night. The comparison was conducted separately for each examined species. A Kolmogorov–Smirnov test (KS test) was used to compare the yellowfin and bigeye tuna length frequency distributions captured by C-hooks versus J-hooks. ANOVA was used to compare the mean length of tunas captured by the experimental treatment and conventional method. The data preparation, figures and statistical analysis were conducted in R (V4.1.2) **(R Development Core Team, 2021)**.



No	Name	Dimension
①	Main line	Φ 2.2 mm
②	Swivel	20 mm long
③	T-type Swivel	20 mm long
④	Branch line	Φ 1.8 mm
⑤	Hook	
⑥	Weight	3 kg

Fig. 2. A tuna hook-and-line attached to the bow (top picture) and a schematic drawing of an oceanic tuna pole-and-line used in this study. The drawing is not drawn to scale

RESULTS

A total of 45 fishing nights were conducted during three fishing trails. In total, 522 and 497 individuals belonging to 16 species and 10 families were captured in C-hooks and J-hooks, respectively (Table 1). From those, 14 species including 486 and 447 individuals were classified as wanted catch (primary and secondary target species) for C-hooks and J-hooks, respectively. The rest of the species contributed to incidental catch (Table 1). The J-hooks caught one olive ridley and one loggerhead sea turtle, whereas none were caught on C-hooks. Yellowfin and bigeye tuna, wahoo (*Acanthocybium solandri*), long snouted lancetfish (*Alepisaurus ferox*), Indo-Pacific sailfish (*Istiophorus platypterus*), and swordfish (*Xiphias gladius*) dominated the catch. Together these six species accounted for 84.1 and 78.7% of the total catch of all species caught by the C-hooks and J-hooks, respectively (Table 1). For the main target species, the yellowfin tuna consisted of 89%, leaving the bigeye tuna accounting for 11% of the catch.

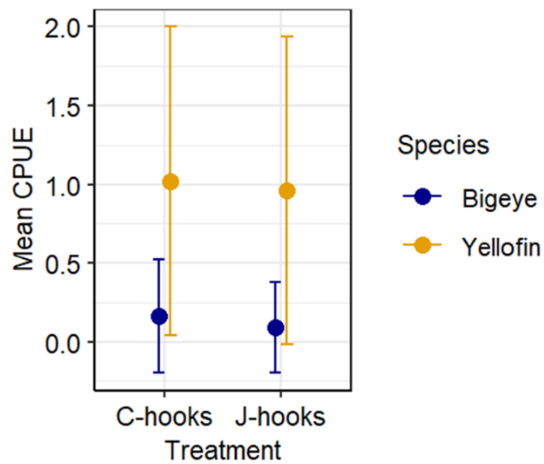


Fig. 3. Mean CPUE (number of individuals per rod per night) of yellowfin and bigeye tunas caught by C-hooks and J-hooks. Bars denote the standard deviation (SD)

Table 1. Summary of sea trials including the number and percent of species caught by different hook types and the statistical analysis using Mann-Whitney U-Test. D is the different in percent between C-hooks and J-hooks and the negative value indicates that C-hooks captured fewer individuals than J-hooks and vice versa. NA is not applicable

Species	**Scientific name**	**Familly**	**Catch in #**		**Catch in %**		**D**	**Mann-Whitney U-Test**	
			C-hooks	**J-hooks**	**C-hooks**	**J-hooks**		**W-value**	***P*-value**
Target species (retained)									
Yellowfin tuna	Thunnus albacares	Scombridae	92	86	17.62	17.30	7.0	4222.5	0.601
Bigeye tuna	Thunnus obesus	Scombridae	14	8	2.68	1.61	75.0	4320	0.174
Bycatch species (retained)									
Wahoo	*Acanthocybium solandri*	Scombridae	111	89	21.26	17.91	24.7	4274	0.502
Long snouted lancetfish	*Alepisaurus ferox*	Alepisauridae	138	128	26.44	25.75	7.8	3993	0.867
Mahi mahi	*Coryphaena hippurus*	Coryphaenidae	12	16	2.30	3.22	-25.0	3870	0.413
Black marlin	*Istiompax indica*	Istiophoridae	4	2	0.77	0.40	100.0	4140	0.410
Indo-Pacific sailfish	*Istiophorus platypterus*	Istiophoridae	22	27	4.21	5.43	-18.5	4040	0.971
Escolar	*Lepidocybium flavobrunneum*	Gempylidae	17	22	3.26	4.43	-22.7	3825	0.368
Blue marlin	*Makaira nigricans*	Istiophoridae	4	7	0.77	1.41	-42.9	3915	0.354
Oil-fish	*Ruvettus pretious*	Gempylidae	13	15	2.49	3.02	-13.3	3960	0.683
Great barracuda	*Sphyraena barracuda*	Sphyraenidae	14	16	2.68	3.22	-12.5	3960	0.692
Swordfish	*Xiphias gladius*	Xiphiidae	45	31	8.62	6.24	45.2	4511.5	0.118
Bycatch (released/discard)									
Loggerhead	*Caretta caretta*	Cheloniidae	0	1	0.00	0.20	N/A	N/A	N/A
Olive ridley	*Lepidochelys olivacea*	Cheloniidae	0	1	0.00	0.20	N/A	N/A	N/A
Thresher shark	*Alopias spp*	Alopiidae	29	37	5.56	7.44	-21.6	4072.5	0.935
Blue shark	*Prionace glauca*	Carcharhinidae	7	11	1.34	2.21	-36.4	3870	0.323

The difference in catch between C-hooks and J-hooks varied from – 42.9 to 100%, which was statistically insignificant for all species (Table 1). The experimental result showed that the C-hooks could capture the wanted species in a comparable amount to the traditional J-hooks. For yellowfin tuna, the CPUE (the number of individuals per rod per night) ranged between 0 and 5 for C-hooks (mean of 1.02 ± 0.98 SD) and between 0 and 4 for J-hooks (mean of 0.96 ± 0.98 SD) (Fig. 3). The maximum CPUE of bigeye tuna caught by both experimental treatments was 1.0 (range from 0 to 1), with mean of 0.16 ± 0.36 SD for C-hooks and 0.09 ± 0.29 SD for J-hooks (Fig. 3).

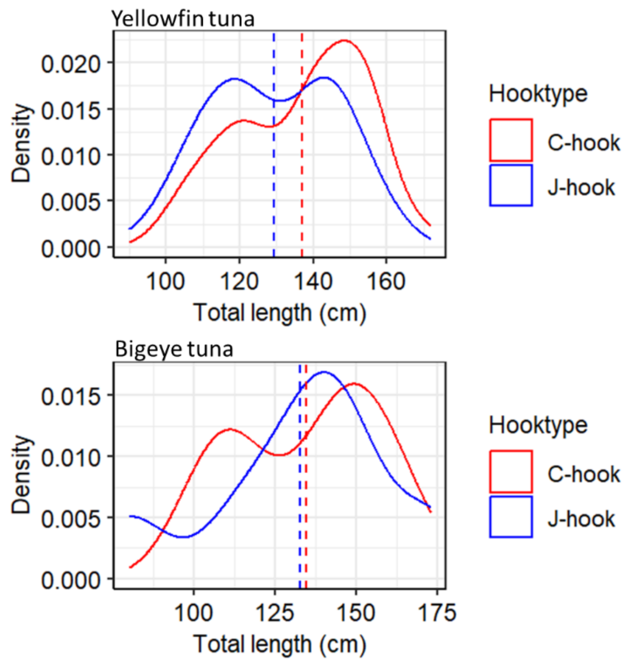


Fig. 4. Total length frequency distribution of yellowfin tuna (top panel) and bigeye tuna caught in the C-hooks (red) and J-hooks (blue). Vertical dashed lines indicate the mean length for each species

The length frequency distribution of the yellowfin and bigeye tuna captured in the C-hooks and J-hooks are shown in Fig. (4), respectively. The mean total length of the yellowfin tuna caught by C-hooks and J-hooks was 136.9cm (range of 100-172cm) and 129.5cm (range of 90-165), corresponding to a weight of 47.4 (range of 16 – 86kg) and 41.2kg (range of 17 – 70kg) respectively. A pairwise comparison of the yellowfin tuna length distribution indicated a significant difference between C-hooks and J-hooks (Kolmogorov-Smirnov test: D = 0.2, *P*-value = 0.04). Results of the ANOVA showed that C-hooks caught yellowfin tuna at larger sizes, compared to the J-hooks (*P*-value = 0.005) (Table 2). C-hooks captured bigeye tuna at a mean length of 134.6cm (range of 103 – 167cm) corresponding with 52.6kg (range of 22 – 98kg), compared to 132.6 cm (range of 80 – 173cm) and 52.9kg (range of 16 – 98kg) at J-hooks. There were no differences in length distribution (Kolmogorov-Smirnov test: D = 0.24, *P*-value = 0.863) and mean (*P*-value =0.863) between the two hook types (Table 2).

Table 2. ANOVA parameter estimates of the effect of hook types on mean length of yellowfin and bigeye tuna. df is degree of freedom

Species	Parameters	df	Sum square	Mean square	F-value	*P*-value
Yellowfin tuna	Hooktypes	1	2417	2417.1	7.91	0.005
	Residuals	172	52540	305.5		
Bigeye tuna	Hooktypes	1	19	19	0.03	0.863
	Residuals	18	11103	616.8		

DISCUSSION

While the ecological benefit of using C-hooks in the pelagic longline fishery has been known, to our best knowledge this is the first time a compressive comparison of catch efficiency in Vietnamese oceanic tuna hook-and-line fisheries using C-hooks against J-hooks has been conducted. Results showed that C-hooks maintained commercial species for both primary and secondary target species. Yellowfin tuna caught on C-hooks were of larger size on average, than those caught on J-hooks. This could improve economic benefits because C-hooks could improve the catching performance in terms of total weight and therefore higher market price expected. This study adds further scientific evidence of the ecological benefit of using C-hooks in hook-and-line fisheries to reduce the incidental catch of sea turtles.

This field study showed that hook-and-line fisheries caught sea turtles at substantially less than the many other pelagic longline fisheries (e.g., Brazilian swordfish, UAS tuna longlines fisheries, and others). For instance, longlines caught an estimate of 0.2 individuals caught per 1000 hooks for Hawaii longline fisheries **(Gilman *et al*., 2007)**, 488 individuals per 54 fishing sets in Costa Rica coast **(Swimmer *et al*., 2011)**, and as many as 83 sea turtles per fishing boat per year for tropical Atlantic Ocean fisheries **(Gilman *et al*., 2007; Gilman & Huang, 2017)**. This is not surprising, since longlines operate a large area of the waters, i.e., as much as two-thirds of the world's oceans **(FAO, 2001)**, which results in more interaction between sea turtles and fishing gear (hooks) as they can be highly migratory and rely heavily on their visual senses and smell in their search for preys **(Nguyen & Winger, 2019)**.

In addition to increasing catch rates, the artificial light used in commercial fisheries increased the bycatch of unwanted species including sea turtles **(Nguyen & Winger, 2019)**. For example, chemical lightsticks used in longline fisheries produce a significant source of stimulus for non-target species and play a role in attracting turtles into the vicinity of longlines **(Wang *et al*., 2007)**, and as a result, the average leatherback incidentally captured in swordfish longline fisheries increased from 0.021 to 0.0311 per

1000 hooks since the use of lightsticks **(Witzell, 1999)**. Therefore, underwater lights used in longlines have been attributed as a major cause of decline in some sea turtle populations **(Witzell, 1999; Watson *et al*., 2005)**. Vietnamese oceanic tuna hook-and-line fishery relies on powerful surface lights to attract the yellowfin and bigeye tunas. This highlights that there is potential for negative trade-offs in situations where artificial light harms or disturbs ecosystem function. Moreover, fishing lights have been shown to alter fish foraging and schooling behavior, spatial distribution, migration, predation risk, and reproduction. For example, the density of predators increased rapidly around the fishing boats when the artificial fishing lights were in function **(Rich & Longcore, 2005)**, and significantly decreased under dark conditions and when fishing lights were turned off **(Thompson, 2013)**. These unnatural behaviors could have a potential effect on the food web regulation of marine organisms **(Becker *et al*., 2013)**. More research on the effect of the surface fishing light in the oceanic tuna hook-and-line fisheries on the vulnerability of threatened, endangered species and marine mammals is therefore needed.

The selectivity of hook-and-lines largely depends on the hook type and size **(Gilman *et al*., 2006)**. However, fishing efficiency can vary between fisheries and species-specific **(Gilman *et al*., 2018)**. Our study showed that C-hooks which were larger in size compared to J-hooks caught more larger yellowfin tuna than J-hooks. This result is similar to **Gilman *et al*. (2018)**, who reported that wider C-hooks captured more large-sized tunas than narrower hooks. **Alós *et al*. (2008)** showed that greater sizes of hooks were more size-selective than smaller hooks, but also caught fewer fish. Although our study showed that there were no differences in catch rates between C-hooks and J-hooks in terms of number, landing volumes of C-hooks were 18% higher because of large fish caught. Therefore, fishermen can gain more economic profits than the traditional J-hooks.

CONCLUSION

This study showed that C-hooks can alter to traditional J-hooks in the tuna hook-and-line fishery to reduce the incidental catch of sea turtles while maintaining the catch rates of target species. The transition requires minimal costs, and modification of fishing gear and vessels. The results contribute to evidence of the ecological benefit of using C-hooks.

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