Aquatic Animals

水生動物 第 2024 巻
令和 6 年 11 月

Determining factors in the survival rate of bycatch green turtles *Chelonia mydas* at a setnet fishery off Nishiki, Taiki-cho, Mie, Japan

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Abstract

Factors influencing the survival proportion of bycatch green turtles, *Chelonia mydas*, captured by a large setnet fishery in coastal waters off Nishiki, Taiki-Cho, Mie, Japan, were investigated. From December 2019 to July 2021, 138 individuals were observed in the net during 44 operations. A Generalized Linear Model analysis revealed that the capture position in the setnet, the standard carapace length (SCL), and the water temperature significantly influenced the survival rate. Survival rate was highest in the chamber net, followed by the large final chamber and the small final chamber, respectively. The chamber net had no net at the top and was open to the sea surface. On the other hand, the tops of final chambers were covered by net, which impedes the turtles' ability to breathe. Larger turtles may breathe using a propulsive force to lift the top net in the final chambers. The survival rate was found to increase with the growth of SCL and to decrease with an increase in water temperature. Therefore, the present study recommends the modification of the net design to provide adequate breathing space to increase the survival rate of bycatch turtles, particularly smaller and less propulsive individuals.

Key words: Green sea turtle; *Chelonia mydas*; bycatch mortality; setnet; case study

Introduction

Extant sea turtles with seven species in two families are widely distributed in temperate and tropical waters of the world. In Japan, the loggerhead turtle (*Caretta caretta*), the green turtle (*Chelonia mydas*), and the hawksbill turtle (*Eretmochelys imbricata*) are recognized as species that nest in the country (Matsuzawa 2012). These three sea turtle species and three other species, except for the flatback turtle *Natator depressus*, are identified as Critically Endangered, Endangered, or Vulnerable on the Red List of the International Union for Conservation of Nature and Natural Resources (IUCN). Hence, these species are the target of conservation and protection measures worldwide.

The population of sea turtles is threatened not only by the reduction in the number of beaches where they nest but also by the negative impact of bycatch in fishing activities. The issue of sea turtle bycatch has been addressed primarily in pelagic fisheries, e.g., by installing Turtle Excluder Devices in trawl nets and using circle hooks and non-squid bait in longline fishing (Miyamoto et al. 2008; Matsuzawa and Kamezaki 2012). An escape gate was developed on the setnet to address the bycatch issue in coastal fisheries (Abe 2006; Tamura et al. 2014). However, the possibility of fish escaping from the gate (Shiozawa et al. 2019) has prevented this measure from being widely adopted. In order to reduce the impact of sea turtle population bycatch in setnets, it is imperative to understand its current state better.

Ishihara et al. (2014) conducted a comprehensive survey among fishermen across Japan and found that the incidence of sea turtle bycatch in large or small setnets was more prevalent than in other types of coastal fishing. They stated that to mitigate the

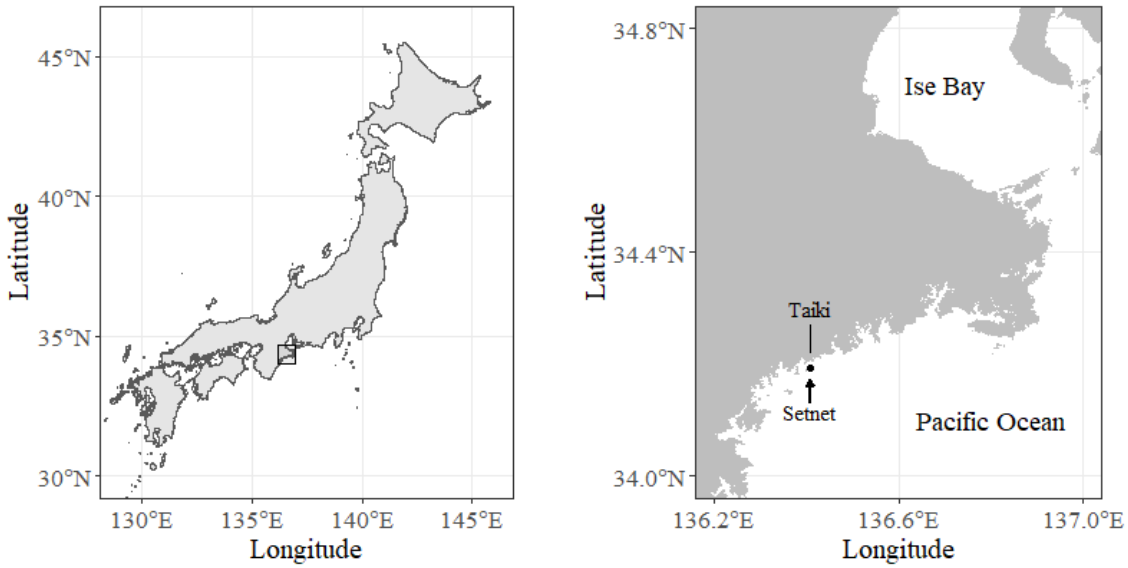

Fig. 1. Study site and surrounding area.

number of dead individuals, a clear understanding of the bycatch situation in each case is necessary because the mortality rate of individuals caught in the same area with the same gear varies. In this context, we investigated the factors influencing the survival rate of green turtles caught in a large setnet fishery off the coast of Nishiki in Taiki-cho, Mie Prefecture. Since drowning is the prominent cause of death of these turtles in setnets, a breathable environment is essential for the survival of sea turtles. The present study examined factors related to breathing (i.e., net type, size of sea turtle, and water temperature) that influence the survival rate in the setnet off Nishiki. Therefore, it showed the potential to reduce sea turtle's bycatch mortality with only minor modifications to the structure of the set net.

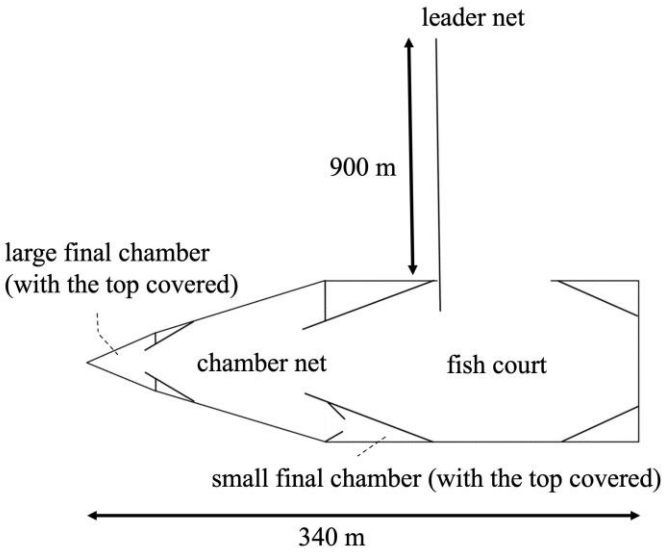

Fig. 2. Schematic drawing of the target setnet.

Materials and Methods

Field sampling

From December 2019 to July 2021, we accompanied a large setnet at the surface off Nishiki, Taiki-cho, Mie, and recorded the bycatches of green turtles. A 340 m wide setnet with a leader length of 900 m has been installed at a depth of 60 m outside Nishiki Bay (34.19 °N, 136.41 °E; Figs. 1 and 2). In this setnet, fishes are guided into the fish court by the leader net and are caught by entering the chamber net and final chamber (Fig. 2). The parts for catches the fishes in the setnet are one chamber net and two final chambers. The two final chambers differ in size, and the tops are covered by net. The turtles were also bycaught in three types of net (chamber net, small chamber net and large chamber net) in setnet. The operation period of the net was from December to July, and the setnet was in place throughout the operation period and were harvested once a day,

except on Tuesdays and Saturdays. The harvesting was not conducted during typhoons or other poor sea conditions. The setnet was harvested 165 times during the survey period. The main target fishes were amberjacks *Seriola* spp., mackerels *Scomber* spp., and barred knifejaw *Oplegnathus fasciatus*.

The species, sex, standard carapace length (SCL), and the condition (whether dead or alive) of bycatch turtles were recorded in this investigation. The number of lateral scutes in the carapace and the shape of the head identified species. The tail is long in maturity males (Wibbels 1999). Sex for individuals with large SCL (more than 80 cm) was determined by tail length, i.e. individuals with extremely long tails protruding from the carapace were classified as males, those with short tails tucked into the carapace as females. Individuals with small SCL (less than 80 cm) were classified unknown sex. For a few bycatch individual that died, their sex was identified by observing the gonads. The net type with bycatch turtles in the setnet (chamber net, large or small final chamber; Fig. 2) and water temperature were recorded as environmental factors. A data logger (Hobo U22-001 Water Temp Pro v2) was installed at the upper part of this setnet to record water temperature. As data loggers could not be installed on one bycatch day in December 2019 and the last bycatch day in July 2020, the lowest overall water temperature and average July water temperature were used for the two days, respectively.

Statistical analysis

Model analysis was performed using R version 4.0.4 software (R Core Team 2021) and a generalized linear model was built using the "glm" function. The response variable was the condition (whether dead or alive) of a bycatch individual for which the probability distribution assumed binomial distribution. The explanatory variables were the type in the net where caught (i.e., chamber net without top net, large final chamber with top net, or small final chamber with top net), SCL, water temperature, harvests interval, number of bycatch individuals caught at one time in the net, and fishing season (2020 season: December 2019 to July 2020; 2021 season: December 2020 to July 2021). The link function was set to a binary logit function. Model selection was conducted based on Akaike Information Criterion (AIC; Akaike 1973) as the indicator, and the model with the smallest AIC was adopted as the optimum model.

Results

138 bycatch green turtles were observed in 44 of the 165 setnet harvests from December 2019 to July 2021. These bycatches mainly occurred from May to July, and only seven bycatches were observed before March (Fig. 3). Of all these bycatch individuals, an individual was identified as male by tail length, 12 individuals as male by gonads, 16 as female by gonads, and the sex of 109 individuals was unknown.

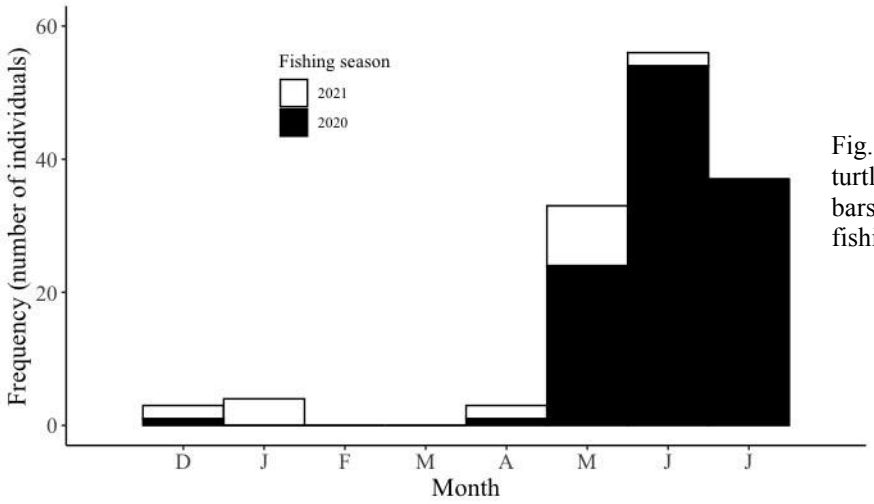

Fig. 3. Number of bycatch green turtles by month. Black and white bars show data of 2020 and 2021 fishing seasons, respectively.

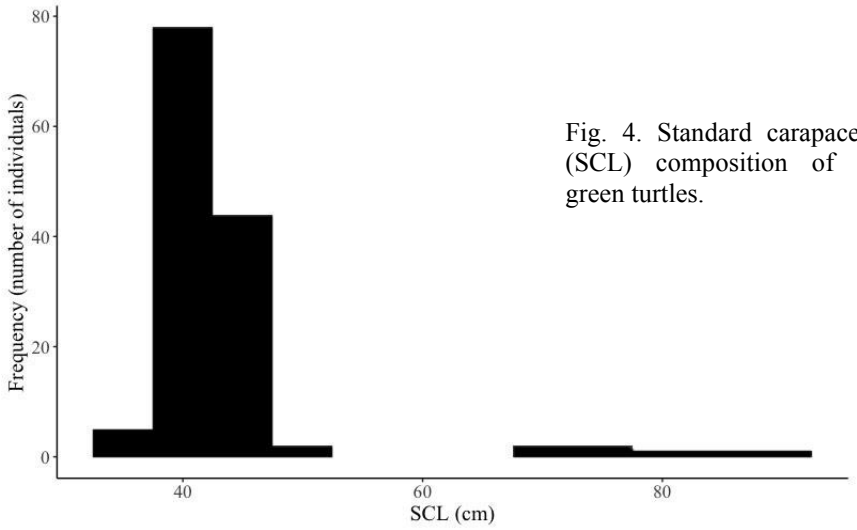

Fig. 4. Standard carapace length (SCL) composition of bycatch green turtles.

Table 1. Results of model selection based on Akaike Information Criterion (AIC).

Model	Explanatory variable						df	logLik	AIC	ΔAIC
	Net	SCL[1]	WT[2]	Int[3]	Num[4]	Season[5]				
1st	+	+	+				5	-65.985	142.0	0.00
2nd	+	+					4	-67.390	142.8	0.81
3rd	+	+	+	+			6	-65.629	143.3	1.29
4th	+	+			+		5	-66.667	143.3	1.36
5th	+	+		+			5	-66.897	143.8	1.82

[1]SCL: standard carapace length, [2]WT: water temperature, [3]Int: harvest interval, [4]Num: number of bycatch individuals in a single harvest, [5]Season: fishing period (2020 or 2021).

Table 2. The result of likelihood ratio test for the optimal model.

Variable	Residuals deviance	Residual DF	Deviance.	DF	χ^2	p
null model	184.96	135	-	-	-	-
net	139.32	133	45.642	2	42.025	<0.001
SCL	134.78	132	4.539	1	4.271	0.039
water temperature	131.97	131	2.809	1	2.809	0.094

The mean SCL of the individuals was 43.6 cm (±8.4 SD), with most having an SCL of 50 cm or less (Fig. 4). A total of 20 individuals were observed in the chamber net, out of which 19 were found to be alive. Among the 87 individuals observed in the large final chamber, 57 were alive. In the small final chamber, only 3 out of 29 individuals were found to be alive. The catch locations in the net of the two individuals were unknown. One of the two individuals with an unknown net location died, and the other survived. Water temperature during the 44 harvests with bycatch ranged between 17.23 and 23.58 °C, with a mean of 20.33 °C (±1.57 °C SD).

The two individuals without records of their location in the net were excluded from the GLM analysis. Since the AIC of the model with catch location, SCL, and water temperature in the net was the smallest, this one was adopted as the optimum model (AIC=142.0; Table 1). The percentage of deviance explained was 29.7% and 28.6% by the initial and optimum models, respectively. The result of the likelihood ratio test for the optimal model is shown in Table 2. Significant differences were observed in net type and SCL. In the optimum model, the survival rate was highest in the

Table 3. Summary of the Generalized Linear Model (GLM).

Coefficients				
Variable	Estimate	SE	z value	Pr (>|z|)
intercept	4.068	4.236	0.960	0.337
net: large final chamber	-2.041	1.065	-1.917	0.055
net: small final chamber	-4.921	1.208	-4.074	< 0.001
SCL	0.091	0.061	1.488	0.137
water temperature	-0.251	0.152	-1.644	0.100

chamber net, followed in order by the large final chamber and the small final chamber. The survival rate increased with the development of the SCL and decreased in higher water temperatures (Table 3). Fig. 5 shows the change in the estimated survival rate with the development of SCL by location within the net. In the chamber net, the change in survival rate with SCL was moderate, generally showing survival rates above 80 %. The survival rate in the large final chamber increased significantly from 50 % to over 90 % with SCL development from 30 cm to 60 cm. The survival rate in the small final chamber was less than 20 % at SCLs of 30 to 50 cm. However, the 95 % confidence interval was extensive due to the lack of data for SCLs larger than 55 cm. The changes in the survival rate with water temperature are shown in Fig. 6. The survival rate decreased by approximately 10 percentage points in the chamber net, around 30 points in the large final chamber, and about 15 points in the small chamber net when water temperature rose from 17 to 24 °C.

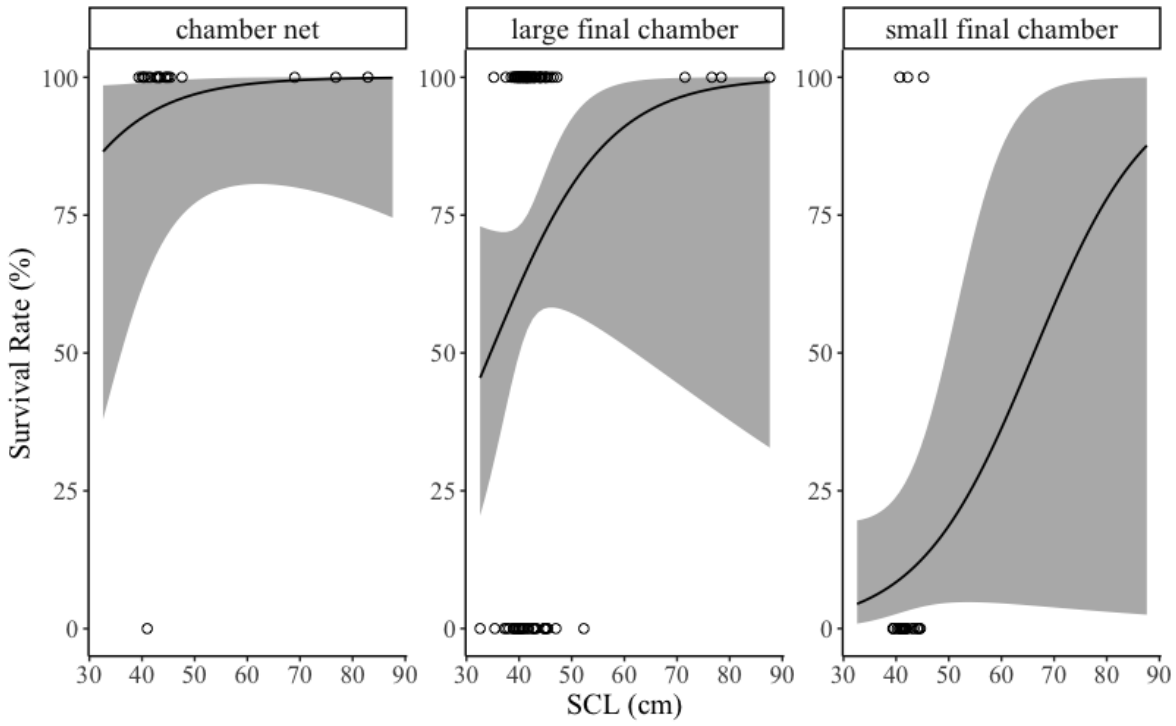

Fig. 5. Estimated values of survival rate of bycatch green turtles by standard carapace length (SCL) and location in the net in the Generalized Linear Model (GLM). Open circles and gray bands show observed data and 95 % confidence intervals, respectively.

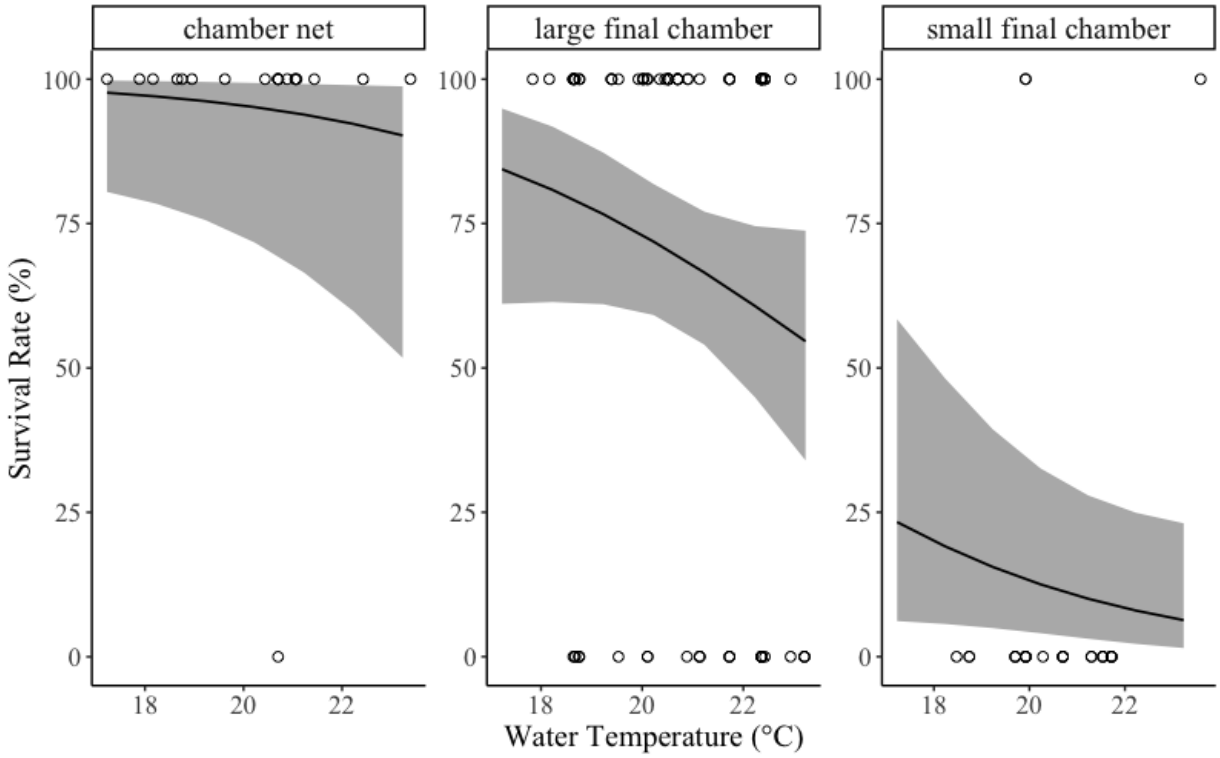

Fig. 6. Estimated values of survival rate of bycatch green turtles by water temperature and location in the net in the Generalized Linear Model (GLM). Open circles and gray bands show observed data and 95 % confidence intervals, respectively.

Discussion

The present study statistically identified factors affecting the survivability of green turtles as bycatch in setnets. Ishihara et al. (2014) suggested that understanding the bycatch situation in each setnet was necessary to reduce bycatch mortality. The results of this study provide essential information for efforts to minimize sea turtle bycatch.

In the GLM analysis, net type, SCL and water temperature were selected as explanatory variables by the AIC, and the effects of those variables on the survival rate were suggested. In particular, significant differences were observed for net type and SCL.

In the chamber net, one of the 20 bycatch green turtles died, and the survival rate in the GLM was more than 80% regardless of SCL. Since green turtles can breathe with their heads above water in the chamber net where the top is not covered, they are less likely to die in the chamber net. In the large final chamber, where the top is covered, 30 of the 87 bycatch green turtles died. The top net of the large final chamber thus probably obstructed the ability of turtles to breathe. The turtle's survival rate in the large final chamber was less than 50 % for SCL around 40cm, and over 90 % for those with an SCL of 70cm or more, as estimated by the GLM analysis. It is known that the propulsive force of sea turtles increases with the development of the SCL: the peak of their propulsive force is greater than 800 N at an SCL of 70 cm and less than 200 N at an SCL of 40 cm (Shiozawa et al. 2016). The larger sea turtles with SCLs of 70 cm or more may breathe by forcibly pushing up the top net, while those with smaller SCLs do not have the strength to push up the top net to breathe, and half of these individuals may drown. In the small final chamber, only three of the 29 individuals survived. The survival rate for individuals with large SCLs was estimated to be over 75 % in the GLM, however, the 95 % confidence interval was extensive in estimating SCLs at 55 cm or more. The

survival rate at small SCLs in the small final chamber was lower than in the large final chamber. Since the top net of the small final chamber is attached more tightly than that of the large final chamber, pushing up the top net of the small final chamber requires more force than that of the large final chamber and results in a lower survival rate.

The survival rate of larger individuals (SCL > 70 cm) was considered to be higher than that of smaller individuals because of their greater propulsive force. In an experiment where captive green turtles were secured to the bottom of the water, it was reported that the turtle's propulsive force decreased significantly after each attempt to surface or move forward (Shiozawa et al. 2016). In the experiment, Shiozawa et al. (2016) observed that turtles with SCLs between 65–75 cm were able to generate a maximum propulsive force of around 800 N, and after four attempts to surface, they were still able to produce a propulsive force exceeding 100 N. On the other hand, turtles with SCLs of 35–45 cm showed a propulsive force of 100–200 N in the first attempt to surface but had only less than 50 N in the fourth attempt (Shiozawa et al. 2016). Observation time was short at about 30 minutes in the experiment, and the turtle could not breathe. The situation with the experiment was thus different from that with the setnet. Even in this setnet, the burden on the sea turtle in the final chamber at each attempt to breathe was greater than its own body weight. The propulsive force of bycatch turtles may decrease due to fatigue, as was similar in the case of the experiments of Shiozawa et al. (2016). The results of the present study indicate that bycatch turtles needed a propulsive force of at least 100 N to have a higher survival rate in the final chamber. In the setnet of this study, to prepare an environment where smaller individuals with a propulsive force of only 20–30 N could breathe and thereby increase their chances to survive, it was necessary to install a float at the top of the final chambers. The small final chamber has a low survival rate for smaller individuals, making it crucial to implement appropriate measures. As of the 2022 fishing season, a large float will be installed in the small final chamber to improve the survival rate of bycatch sea turtles. This measure is expected to have a positive impact.

In the GLM analysis, the survival rates were lower when water temperatures were higher. Penick et al. (1998) reported that the muscles of green turtles consumed more oxygen at higher water temperatures. In loggerhead turtles, it has also been reported that the maximum dive time decreased from about 400 to 100 minutes when water temperatures increased from about 15 to 23 °C (Hochscheid et al. 2005). Breathing intervals are therefore expected to become shorter, and the green turtles rise to the surface more frequently with increases in water temperature. In the setnet of the present study, the propulsive force likely decreased due to a higher frequency of attempts to push up the net for breathing when water temperatures were higher, and in the end, it became more difficult to push up the net to breathe.

The results of the present study showed that the number of bycatch individuals was biased by fishing season and month. In addition, the SCL composition of bycatch individuals was biased toward smaller individuals. A future study will need to clarify the environmental factors and individual characteristics likely to cause bycatch to occur in the setnet.

Acknowledgements

We are grateful to Ayana Higashi and other Fish Population Dynamics Laboratory members, Graduate School of Bioresources, Mie University, for their assistance with on-board recording and dissection of the green turtle bycatch. We would like to thank Kei Okamoto of the Japan Fisheries Research and Education Agency for his advice on species identification and sex determination of sea turtles, Daichi Sasaki for providing water temperature data, and Douglas Braat for the English language review.

We also thank members of the Miegaiwan Fisheries Cooperative Association and employees of Toto Kin for agreeing to take us on their fishing boats and for providing us with a place to dissect sea turtles. Finally, we thank the reviewers and editors of this article.

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Received: 22 July 2024 | Accepted: 14 November 2024 | Published: 23 November 2024