Preliminary result of horizontal and vertical movements of swordfish in the North-west Pacific; A note of swimming behavior of single swordfish.[1]

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Abstract

The tagging studies of swordfish using electrical tags were have been performed in the world although the long-term observations (more than half year) were reported in only 6 individuals in the North west Pacific. It needs more observation for understanding their migration. Hence, we performed tagging for swordfish to collect long-term tracking data using PSATs in the North west Pacific. Tagging swordfish were caught by pelagic longline, tagged for the individual having active condition. Two tagging methods, tagging on the deck and on the water, were performed in this study. As a result, a swordfish tagged on the deck was flouted in water surface after release, were caught with PSATs. On the other hands, a swordfish tagged on the water swam away actively and dying sign was not observed, long-term observation data among 172 days were collected. In the horizontal movement, the wide migration was not observed, and did not move across Kuroshio extension. There is a possibility that this swordfish had been stay the breeding ground. In the vertical movement, this swordfish showed daily vertical movement as well as previous study. In daytime, this fish falls to depth 500–800m, usually stayed at about depth 600m. In April to early June, secondary diving to about depth 800m was observed. This is seventh long-term observation in the North west Pacific. However, the long-term observation is not so many, it is necessary to accumulate further tracking data to clarify the migration pattern in the North west Pacific and population connectivity in other area.

Introduction

The tagging studies for swordfish using electrical tags have been performed in the world. In the North west Pacific (N. W. Pacific), Takahashi et al. (2003) and Tanaka & Yamaguti (2017) reported their migration using by archival tag and pop-up satellite archival tags (PSATs), respectively. Takahashi et al. (2003) indicated a possibility of seasonal migration based on an estimation of horizontal trajectory for single individual released from offshore of Miyagi prefecture Japan; the swordfish stayed in the Oyashio area during in winter and in the subtropics area in summer. Tanaka & Yamaguti (2017) reported their migrations based on the tracking data (11–300 days) collected from 21 individuals near Ogasawara Island. Most of them did not exhibit long-distance migration beyond the N. W. Pacific area. However, horizontal migration of swordfish is various, they could not observe common migration pattern in the N. W. Pacific. The swordfish is well known to show clear daily vertical movements between daytime and nighttime, and they regularly dived to depth about 250–700m in daytime, and about 0–50m in nighttime (Takahashi et al., 2003, Tanaka & Yamaguti 2017). The swimming depth in daytime is different among Oyashio area and subtropics area (Takahashi et al., 2003). However, the amount of long-term observation (more than half year) in the N. W. Pacific is

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not large, collected from only 6 individuals. The migration information is importance to understand population structure. Hence, it is necessary to accumulate more observation of horizontal and vertical.

Tagging procedures are important for long-term tracking of animals. Especially, the handling time from catch to release is directly connected for the after condition of tagged fishes. For example, Tanaka & Yamaguti (2017) succeeded using vertical longline in the long-term observation by shorting times from hook to release. Further, the handling methods is also important. For example, tagging on the deck can obtain detail measurements and accumulate tagging but does damage to fish. On the other hand, in tagging on the water, the damages for fish is smaller than former methods but we can obtain only rough measurements (i.e., estimated size). In this study, we challenge two tagging methods, on the deck and on the water, considered the damages for target fish.

In this study, we report the record of movement of a swordfish released in offshore using pelagic longline, and could succeed in estimating horizontal and vertical movement for 172 days (nearly half-year). And, we introduce the tagging methods used this study.

Material and Methods

Tagging procedures

The tagging experiment of the wild swordfishes were captured by shallow set longline (depth 42–70m, mean depth 53m) by chartered R/V No.37 Den-maru in the N. W. Pacific. The longlines were soaked for about 12 hours in nighttime. The target was selected as an individual with active condition. A MiniPAT (Wildlife Computers, Redmond, WA, USA) was attached to swordfishes by darting a plastic umbrella dart into the pterygiophore of the first dorsal fin using harpoon (Fig. 1A and B). In this study, two patterns of tagging were performed, i.e., tagging on deck and in the water. In tagging on deck, a target swordfish was brought on board, and eye-fork length (EFL) was measured to the nearest cm with caliper. Then, a PSAT was tagged by harpoon (Fig. A), and released. In tagging in the water, a target swordfish was attracted to ship, a PSAT was tagged by harpoon, and released. EFL was estimated by visual observation. The line was cut without removing the hook at release. Tagged swordfishes were 170 cm EFL and est. 140cm EFL, and release localities were 28°52‘N, 150°17’E and 27°34‘N, 149°5.5’E, respectively.

Tag analyses

The PSAT archived the ambient sea water temperature, depth at 10 minutes intervals, and light intensity after the tagged swordfish was released. PSAT was programed to start transmitting data

via ARGOS satellite system and to detach from the swordfish after 240 days. The tag was also programmed to automatically detach under the condition of a constant depth recorded over five days or after exceeding a depth of 1,700m to prevent the tag from being crushed.
The geolocation between the release and pop-up location was estimated using the tag manufacturer's proprietary geolocation processing estimator, Global Position Estimator version 3 (GPE3), which is based on a hidden Markov state-space model with 0.25×0.25 grid spacing.

The time-series data for depth and temperature were classified into the subsets day (dawn to dusk) and night (dusk to dawn). Dawn was defined as the start of civil twilight, and dusk was defined as the end of civil twilight. The differences in the depth distribution and vertical thermal distributions between day and night were tested using the Wilcoxon rank-sum test.

Result and Discussion

Deployment of tag

In tagging on the deck, the tagged swordfish were observed slowly swimming to under the water. However, we caught again this individual because it had floating on surface after few minutes. It was suggested that the landing on the deck would cause large damage for the fish and the success rate of obtaining long-term data would be significantly reduced.

In tagging in the water, the tagged swordfish swam away actively and dying sign (i.e., floating after release) was not observed. As a result, the data for 172 days were obtained (20th April to 9th October). Although we programmed the tag to detach from the fish after 240 days, the PSAT detached prematurely. In this study, we considered no operational or methodological problem about tagging in the water. Additional tests are necessary to evaluate success rate of this tagging method.

Horizontal movements

The wide migration was not observed in this swordfish, this fish stayed in the N. W. Pacific area, and did not move across Kuroshio extension (Fig.2). This individual moved in a southerly direction from April to May, then they moved in a northerly direction from June to July and stayed in about 30°N among August to October. This migration pattern among August to October was similar to the tendency reported by Tanaka & Yamaguti (2017). Tanaka & Yamaguti (2017) estimated swordfish staying in spawning ground in this season, i.e., the area over 24 °C in the annual average sea surface temperature (Nishikawa & Ueyanagi, 1974). Because sexual maturities size of swordfish in 50% sexual maturity size are 102.0cm EFL in male and 143.6cm EFL in females (ISC 2018), and it is possible that this fish has been reached to maturity size even if male or female. Hence, there is a possibility that it had been stay this area for breeding.

Vertical movements

The swordfish showed clear daily vertical movement, and in nighttime the swordfish inhabited depths shallower than depth 100m, and at daytime from depth 500–800m (maximum: depth 1,252m), dropped in dusk and rise in dawn (Fig.3). The ambient temperature experienced ranged from 4.8 to 29.4°C (mean: 23.9°C) in nighttime, and from 3.1 to 29.9°C (mean: 9.0°C) at daytime. For this individual, the depths and temperatures experienced in daytime were significantly deeper and colder than those experienced at nighttime (Wilcoxon rank-sum test, $p < 0.001$).

Two patterns of depth distribution in daytime were observed during the period (Fig.3). This swordfish usually stayed in about depth 600m, but also stayed about depth 800m among from April to early June (Fig. 4A). When diving until depth 800m, this individual dived two steps; this individual stayed about depth 600m in the first, and after further dived to about depth 800m. This movement patterns had been observed after 9:00 (JST) at least. Further, this depth transition takes place immediately, and it was considered that the movement to about depth 800m is secondary diving. Interestingly, it had not risen until next dawn after dive, and it did not return to about depth 600m, too. The distribution of the day with this secondary diving was not observed every day among from April to early June, both diving pattern were observed in this period (Fig. 4B). This secondary diving was not reported in Takahashi et al. (2003) and Tanaka & Yamaguti (2017). Although it is reported that the depth during daytime depends on the deep scattering layer (DSL; Dewar et al., 2011), it is not understanding the relationships between this behavior and DSL. This behavior may occur due to the difference of environmental structure (e.g., vertical structure of water column). According to temperature and depth profiles of this individual, the clear thermocline at about depth 150–300m had not been formed in the period doing secondary diving (Fig. 5). However, further observation data is needs for clear to the reason.

The basking behavior was observed 1 to 5 times per month without April, and there were the cases of two times in a day or 2 consecutive days (Fig. 4B). In August, the records of depth 0m were only one day in August but it was considered that this was error in the depth sensor due to mismatch with surface water temperature in the other days And this temperature was matching the temperature of the water depth zone around depth 600m, i.e. estimated swimming depth (Fig. 4A). Hence, it is not considered by the basking behavior.

In this study, successful the long-term movement was observed using pelagic longline, this is seventh individuals obtained long-term movement in the N. W. Pacific. However, total amount of long-term observations is still small in the N. W. Pacific. And it is necessary to accumulate further tracking data to clarify the migration pattern and population connectivity of this species.

The highly migratory fish may behave differently depending on the gender, e.g., the different migration by sex has been suggested by the analysis of diet and maturation of blue marlin (Shimose et al., 2012). However, the gender of billfish including swordfish is unknown without their dissection and observation of gonads. Recently, the gender discrimination markers using DNA have been developed in bluefin tuna (Suda et al., 2019). It would be possible to develop that marker for swordfish. If the methodology is developed and the tissue can be sampled at their release in non-lethal manner, it may be possible to understand the sex specific migration pattern. In future study, it is necessary to consider the advanced release methods including tissue sampling for more comprehensive understanding in their behavior.

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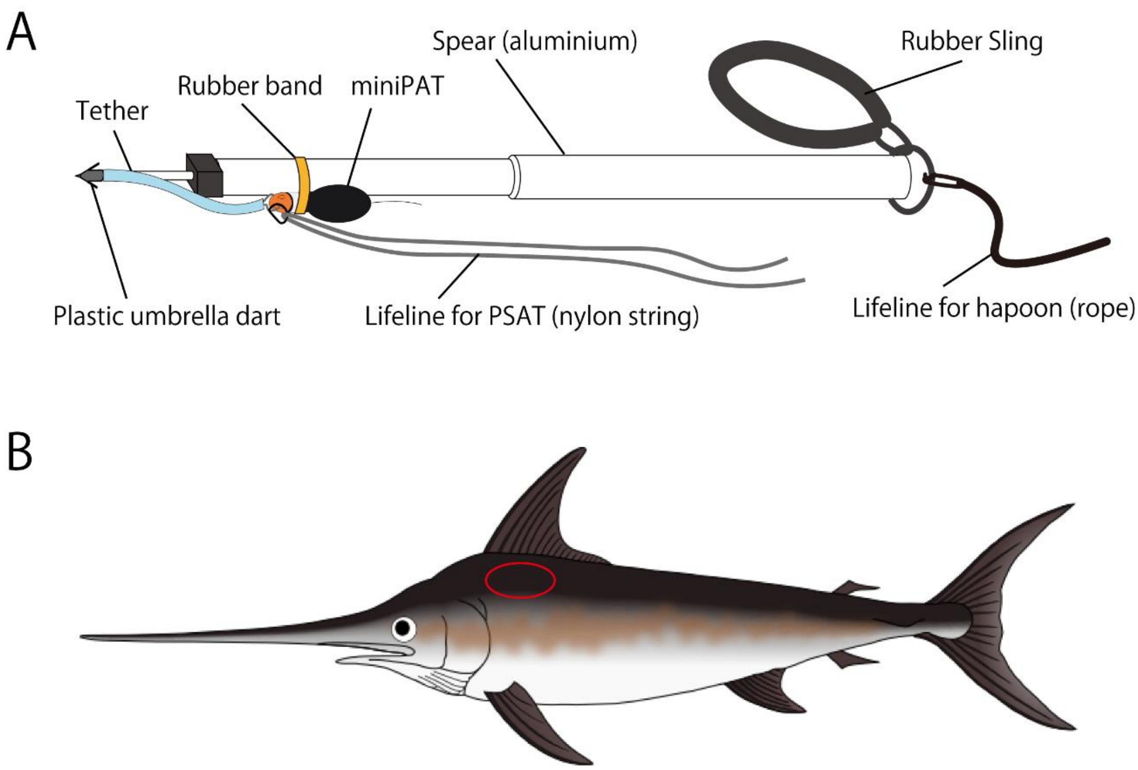

Fig. 1 Applicator tool (**A**) and tagging positions (**B**) in our tagging protocol. Red circle show target position both in deck and water.

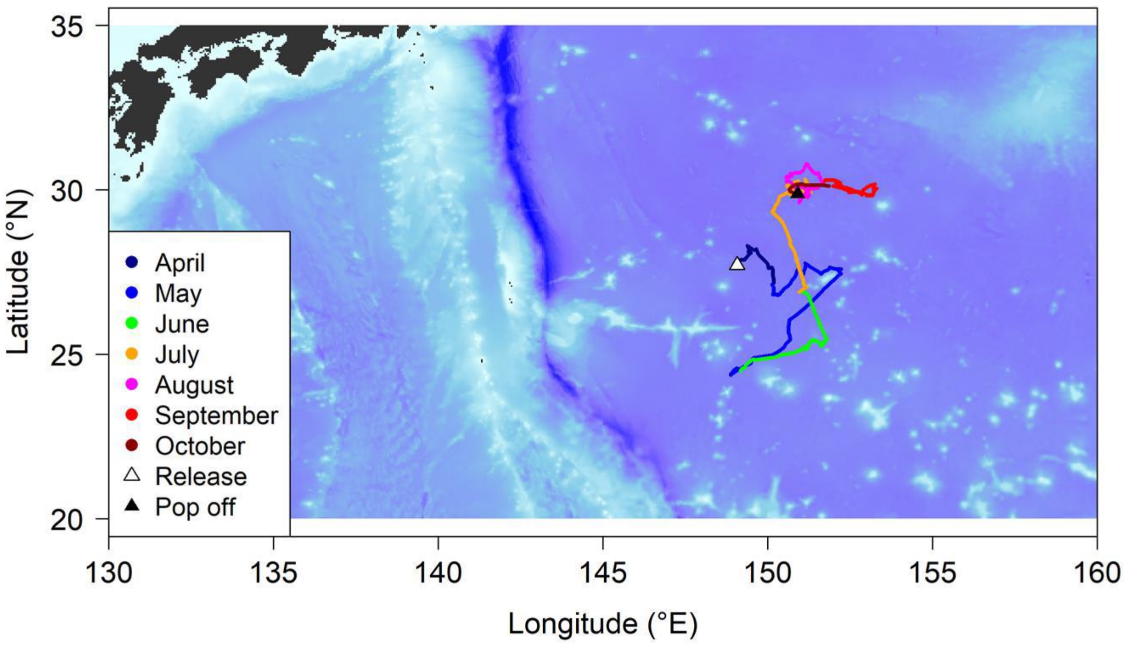

Fig. 2 Horizontal movements of swordfish in the North west Pacific. Open triangle denotes location of swordfish released with a PSAT; solid triangle denotes pop-up location of the PSAT.

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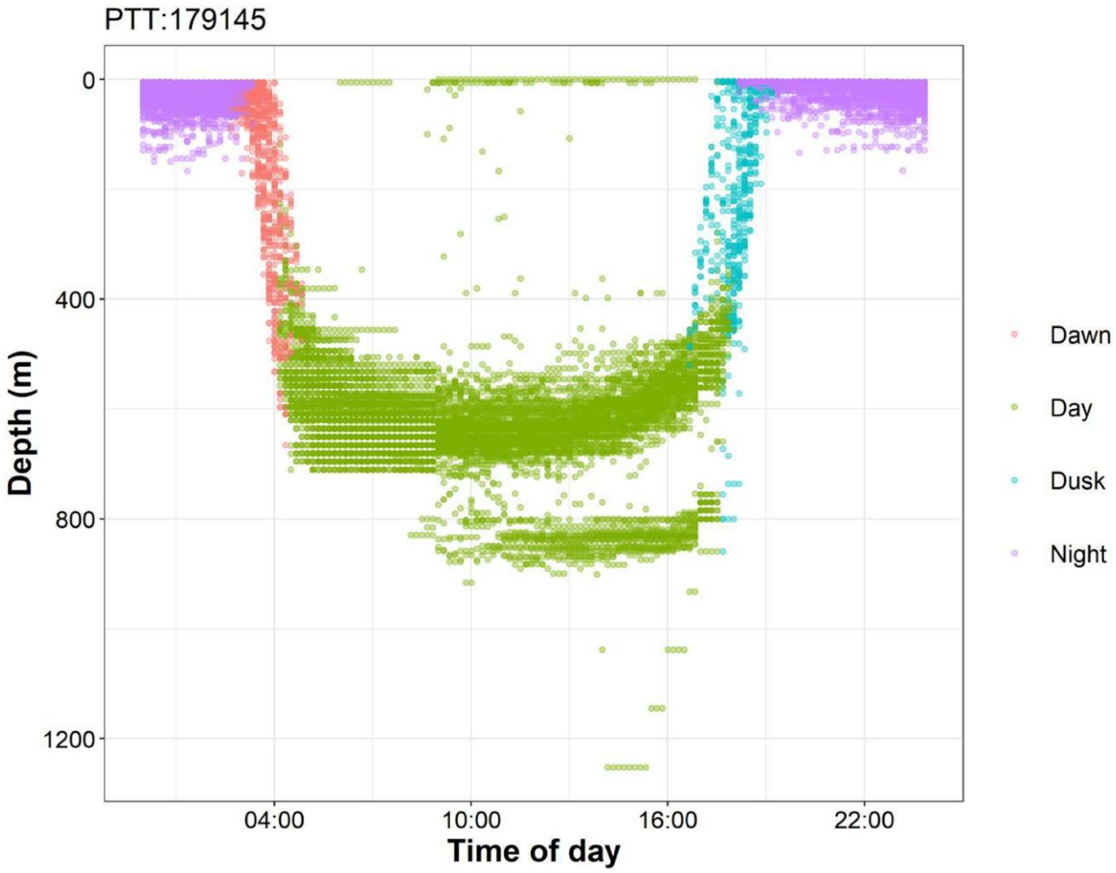

Fig. 3 Diel **v**ertical distributions of swordfish in the North west Pacific. The data among 172 days was aggregated and plotted in 24 hours.

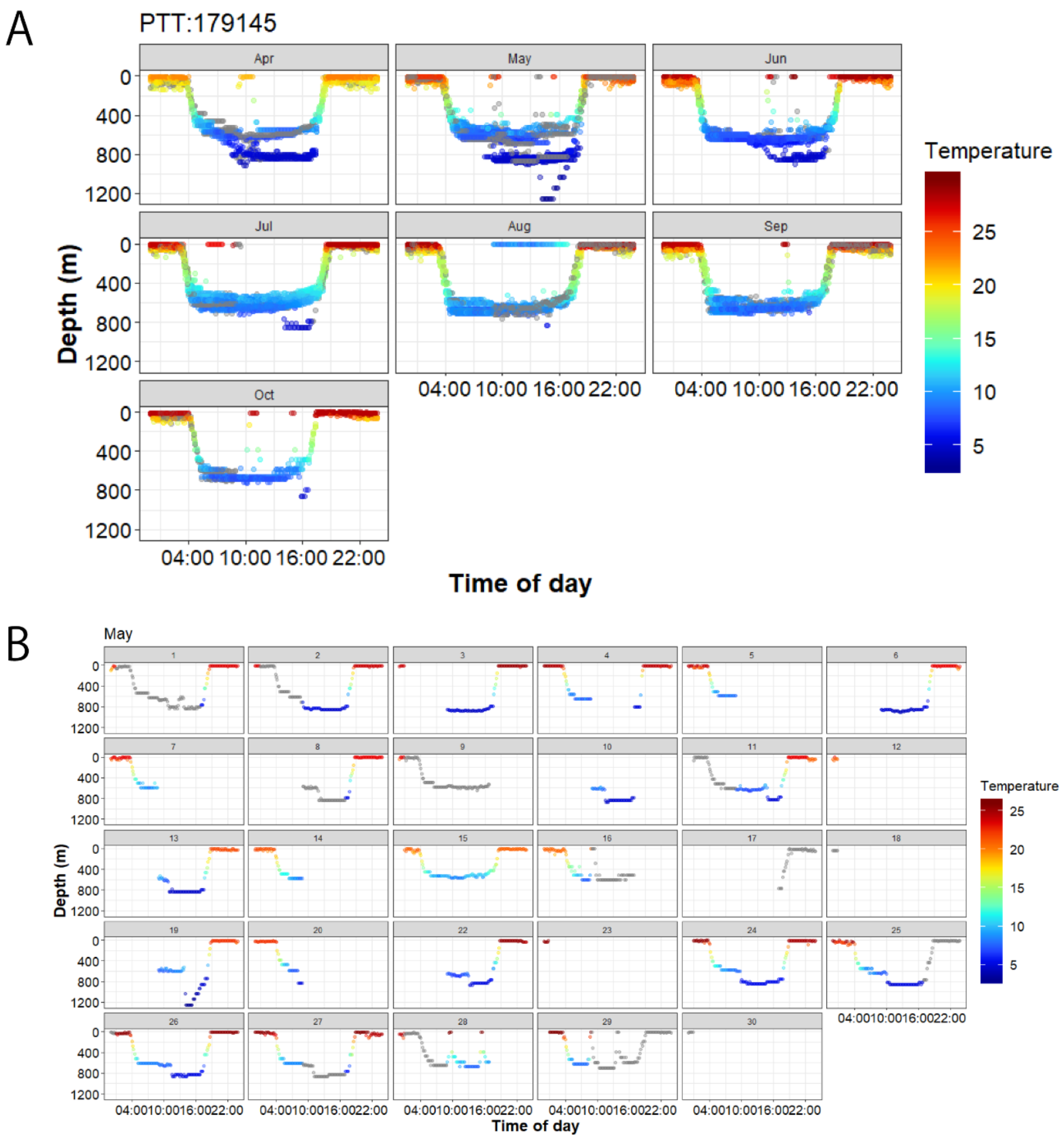

Fig. 4 Diel vertical movements by month (A) and by day in May (B). Point colors show temperatures in each depth according color chart, gray points show missing of temperature data.

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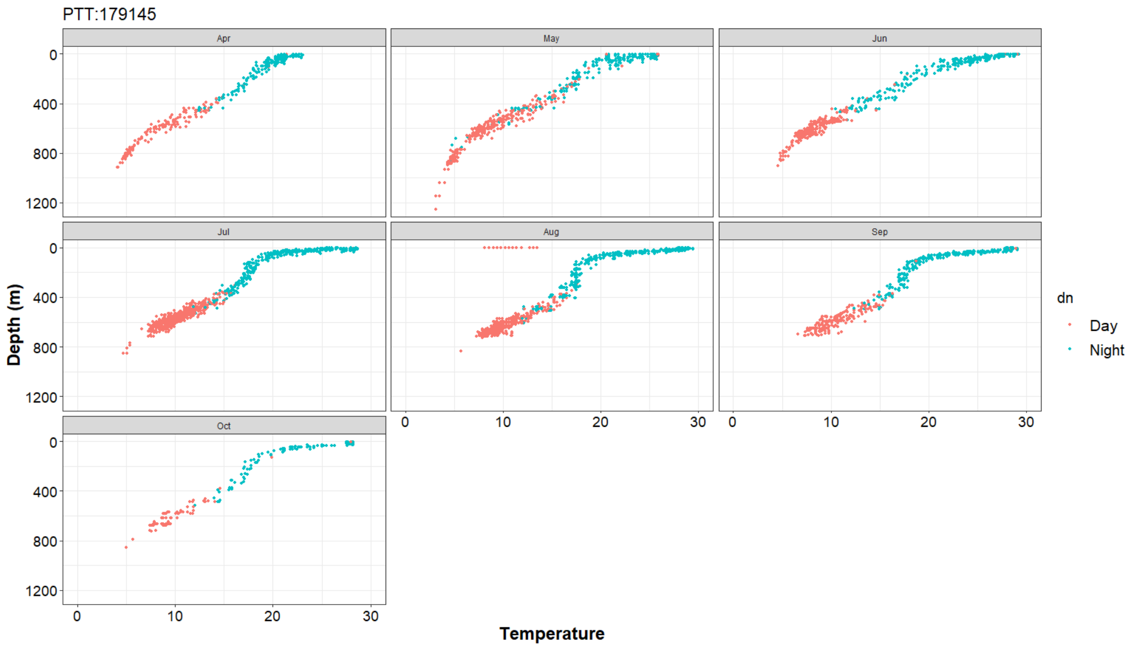

Fig. 5 Monthly temperature-depth profiles collected from tagged swordfish in the North west Pacific.