ISC/21/SHARKWG-2/09

Progress report of collaborative study on the migration pattern of blue shark (*Prionace glauca*) in the central North Pacific Ocean[1]

Yasuko Semba[2], Yuki Fujinami[2], Melanie Hutchinson[3], Michael J. Kinney[4], and Mikihiko Kai[2]

[2] Fisheries Resources Institute, Japan Fisheries and Education Agency.
5-7-1, Orido, Shimizu-ward, Shizuoka City, Shizuoka Pref., Japan.
senbamak@affrc.go.jp

[3] Cooperative Institute for Marine and Atmospheric Research, Pacific Islands Fisheries Science Center

[4] NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu, Hawaii USA

[1] Working document submitted to the ISC Shark Working Group Workshop, 9-19 November 2021, Web-meeting. **Document not to be cited without author's permission.**

Abstract

A collaborative study to investigate the migration patterns of blue shark (*Prionace glauca*) in the central North Pacific Ocean was launched between Japan and the US in 2020. Ten pop-up satellite archival tags (PSATs) provided by Japan were distributed to US longline observers onboard commercial Hawaiian longline fishery vessels between 2020 and 2021 in association with US scientists. As of the end of October 2021, all PSATs had been successfully attached to blue sharks. Among the ten PSATs, three had troubles with their depth sensor and/or archival of data, and two had no data transmissions after the preset pop-off date. We obtained data from one adult female consisting of 226 days-at-liberty, this female exhibited a clockwise movement pattern (from the southwestern waters off Hawaii towards the US mainland) between January and August 2021 with spatiotemporal variation of vertical behavior. The remaining four PSATs currently still attached to sharks are programmed to detach from February -June of 2022.

Introduction

At the ISC Shark working group held in December 2019, a collaborative study on biological parameters and fishery data for blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) was discussed. Tagging studies for these species was identified as “high priority” in terms of helping to establish spatial distribution by size and sex and transboundary movement across the equator or the international dateline (ISC 2020).

Migration patterns of blue shark in the North Pacific have been estimated or reported based on large-scale fishery data (Nakano 1994) and tagging studies with conventional tags (Sippel et al. 2011) and pop-up satellite archival tags (PSAT) in the northwestern (Fujinami et al. 2021), central (Musyl et al. 2011) and northeastern Pacific (Nosal et al. 2019). In the northwestern study, adult females exhibited large-scale latitudinal and longitudinal migration, but trans-Pacific migration was not observed. In the northeastern study, the Southern California Bight (SCB) ecoregion and exclusive economic zones of the USA and Mexico was found to be part of an important nursery area for this species (Nosal et al. 2019). At the same time, numerous blue sharks tagged in the northeastern Pacific moved to the central and northwestern Pacific, and most of them were recaptured near the eastern equatorial Pacific (Sippel et al. 2011). In the central north Pacific, released sharks showed latitudinal and longitudinal movement, but consistent trends have not been fully confirmed yet (Musyl et al. 2011). At present, the understanding of migration patterns for adult blue sharks in the central and northeastern Pacific is not necessarily sufficient to interpret the genetic population structure of this stock (not genetically differentiated within the North Pacific; King et al. 2015, among Indo-Pacific; Taguchi et al. 2015) in spite of at least two nursery areas reported in the area off Japan and in SCB.

In this paper we will discuss progress of the recent Japan (Fisheries Resources Institute; FRI) and USA (Pacific Islands Fisheries Science Center in Hawaii; PIFSC) collaborative study to investigate

the migration pattern of blue shark in the central North Pacific Ocean by summarizing the outline of the project and presenting preliminary outcomes.

Materials and Method

In 2020, Japan purchased 10 PSATs (MiniPAT, Wildlife Computer) and provided them to PIFSC where Dr. Hutchinson cooperated to arrange tagging by observers onboard commercial fishing Hawaiian tuna longline vessels.

Following the protocol used in the US tagging program, tags were configured with a "stainless steel tether measuring 15 cm long with a small titanium anchor attached". The tags were programmed to automatically detach from individual sharks if 1) 240 days elapsed since release, 2) the individual showed no vertical movement (within a range of ± 2.5 m) over five days, or 3) the shark sunk to a depth greater than 1,700 m.

Blue sharks captured by longliners were brought alongside the vessel after the observer checked if it was alive and in good condition. The tagging dart was inserted into the dorsal musculature below the first-dorsal fin using a tagging pole while sharks remained in the water. Once tags were secure the fishing line was cut and the shark was released.

Results and Discussion

As of October 13th 2021, US scientific observers onboard longline vessel have attached all ten PSATs in the area ranging from 15°N -166°W and 22°N-151°W (Figure 1). Table1 shows detailed information including date of tagging, estimated fork length (FL) and sex of nine blue sharks tagged and released (data of the last tag released in Oct. 2021 is under processing).

Six of the nine tagged sharks were female, of which five were adults and one was a subadult, based on the length-at-50% maturity (156.6 cm in precaudal length: PCL) estimated by Fujinami et al. (2017). Sex of the other three individuals was unknown, but all of them were likely adults as their body length was over 200 cm, which is larger than length-at-50% maturity of both sexes (male: 161 cm in PCL). The tenth tag was very recently deployed and the deployment details are not yet available.

Programmed release date of PSATs for six of the nine tags deployed has already elapsed unfortunately, with normal movement data obtained from only one individual (# 204665). For #204656 and #204660, data between December and March was not recorded and a malfunction of the depth sensor was suspected for #204656 and #204662. In addition, pop-off of #204658 (released date: November 30th, 2020) and #204661 (#released date: January 15th, 2021) was not confirmed. We are currently making inquiries with the tags manufacturer via their agent in Japan about these malfunctions.

Regarding #204665 (approximate FL: 244 cm) released on 24th January in 2021, 226 days of movement data were obtained. This adult female moved in a northeastern direction between January and March and reached at 33.7°N at the end of March (Figure 2). During this period, she experienced

drastic changes in the environment (Figure 3). Between January and February, she swam through an area in which the water temperature of the epipelagic zone (between sea surface and 200 m) was above 20℃. In March, she experienced much colder water with sea surface temperature lower than 20℃, and her diving depth gradually became shallower. This shark stopped its northward migration around the end of March and moved eastward towards California before starting a southwestward movement from around mid-April until early July. Maximum diving depth was shallowest around mid-April and became deeper with increasing temperatures as it moved southward. After reaching 14.8°N, 159°W in mid-July, she moved northward around the island of Oahu.

Although it was not confirmed whether this female was pregnant at release, it has shown a similar movement pattern to that of a pregnant female observed in the northwestern Pacific (Fujinami et al. 2021) in that the pregnant females moved in a northward direction from subtropical to temperate waters and then returned to subtropical waters. According to Hanan et al. (1993), SCB is a major pupping area and generally considered a nursery area for immature blue sharks, which is supported by a fishery-independent longline survey conducted in the US sector of the SCB ecoregion from 1994–2013, indicating 81% of blue sharks was immature (Runcie et al. 2016) ,. Therefore, movement pattern of adult sharks migrating into and out pupping area in SCB is very important theme of study. It is expected that further analysis for the remaining individuals may provide insight into the migration pattern of adult blue sharks inhabiting in the central North Pacific.

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Table1. Brief summary of blue sharks tagged by US observers as of the end of October 2021. FL: fork length. Location of deployment was shown in Figure1. The tenth tag was very recently deployed and the deployment details are not yet available.

ID	Approximate FL (cm)	Sex	Date of deployment (HST)	Pop-up Date (UTC)	Pop-up Latitude (North)	Pop-up Longitude (West)	Days at liberty	Brief explanation of current situation.
204656	183	F	2020/11/29	2021/3/14	19.00	150.61	104.6	Issue of depth sensor and data gap (now inquiring)
204660	152	F	2020/11/29	2021/4/20	26.07	151.48	141.2	Issue of data gap (now inquiring). Predated by endothermic animal.
204658	183	F	2020/11/30					Not popped up (now inquiring)
204665	244	F	2021/1/14	2021/8/29	20.89	158.62	225.9	
204661	213	U	2021/1/15					Not popped up (now inquiring)
204664	213	F	2021/6/14					-
204662	244	U	2021/6/14	2021/6/23	17.21	163.09	7.9	Issue of Depth sensor (now inquiring)
204659	213	U	2021/9/10					-
204663	244	F	2021/9/10					-

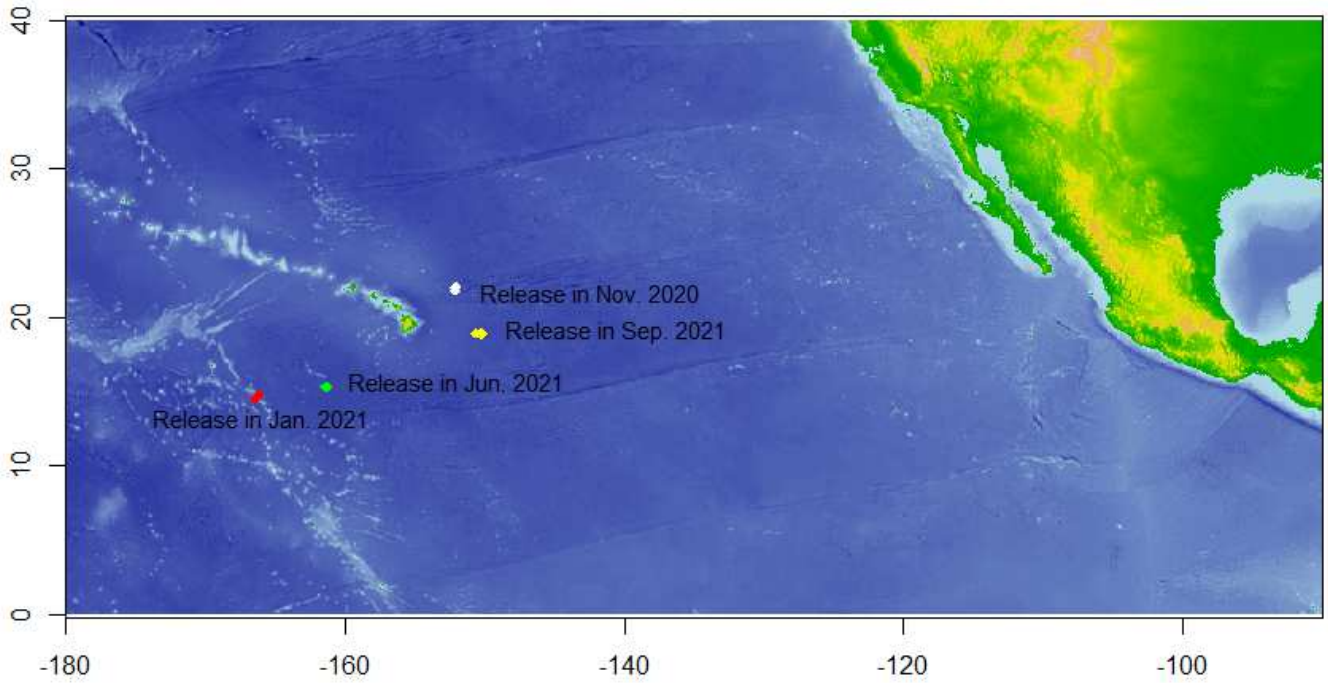

Figure 1. Location of release for nine blue sharks by trip. Detailed information by individuals are shown in Table1.

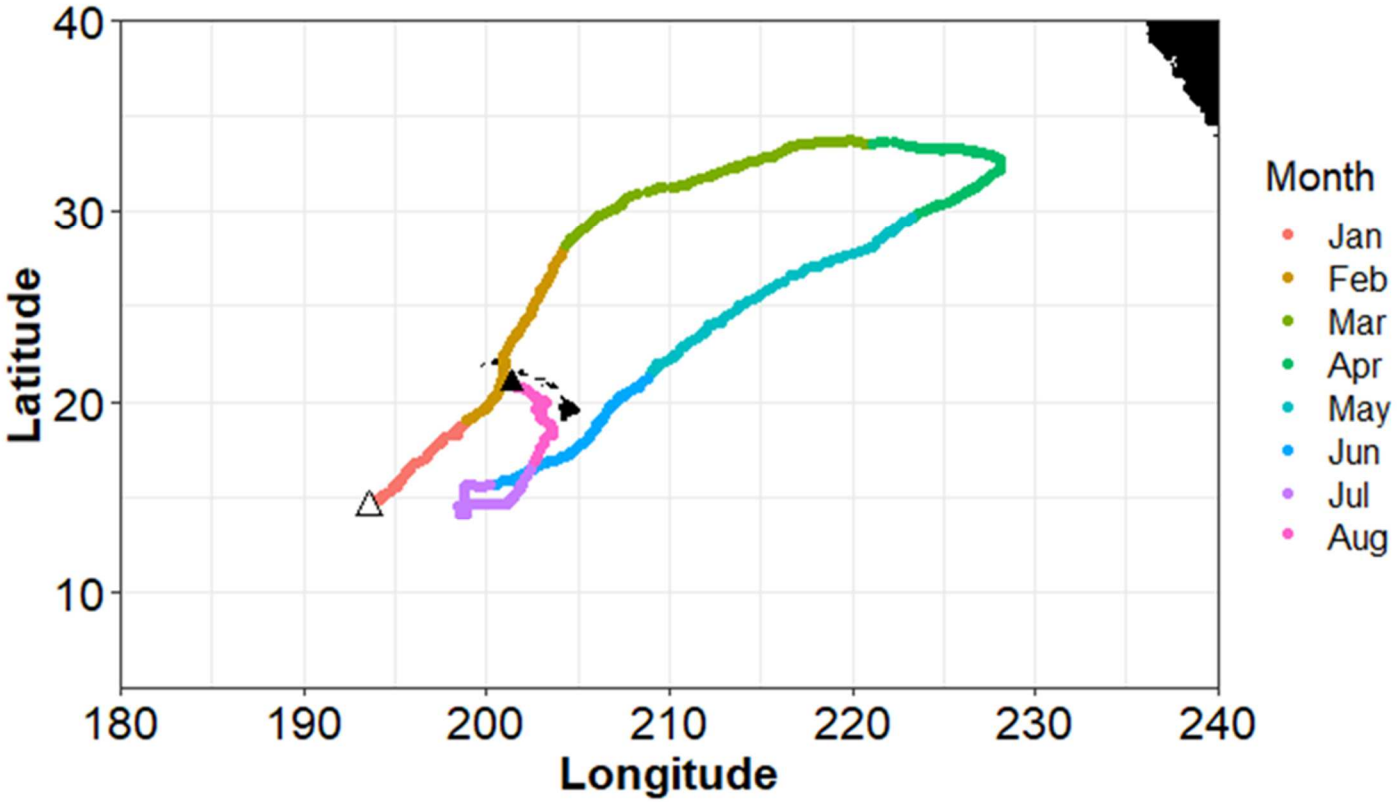

Figure 2. Monthly movement pattern for tagged female blue shark (#204665).

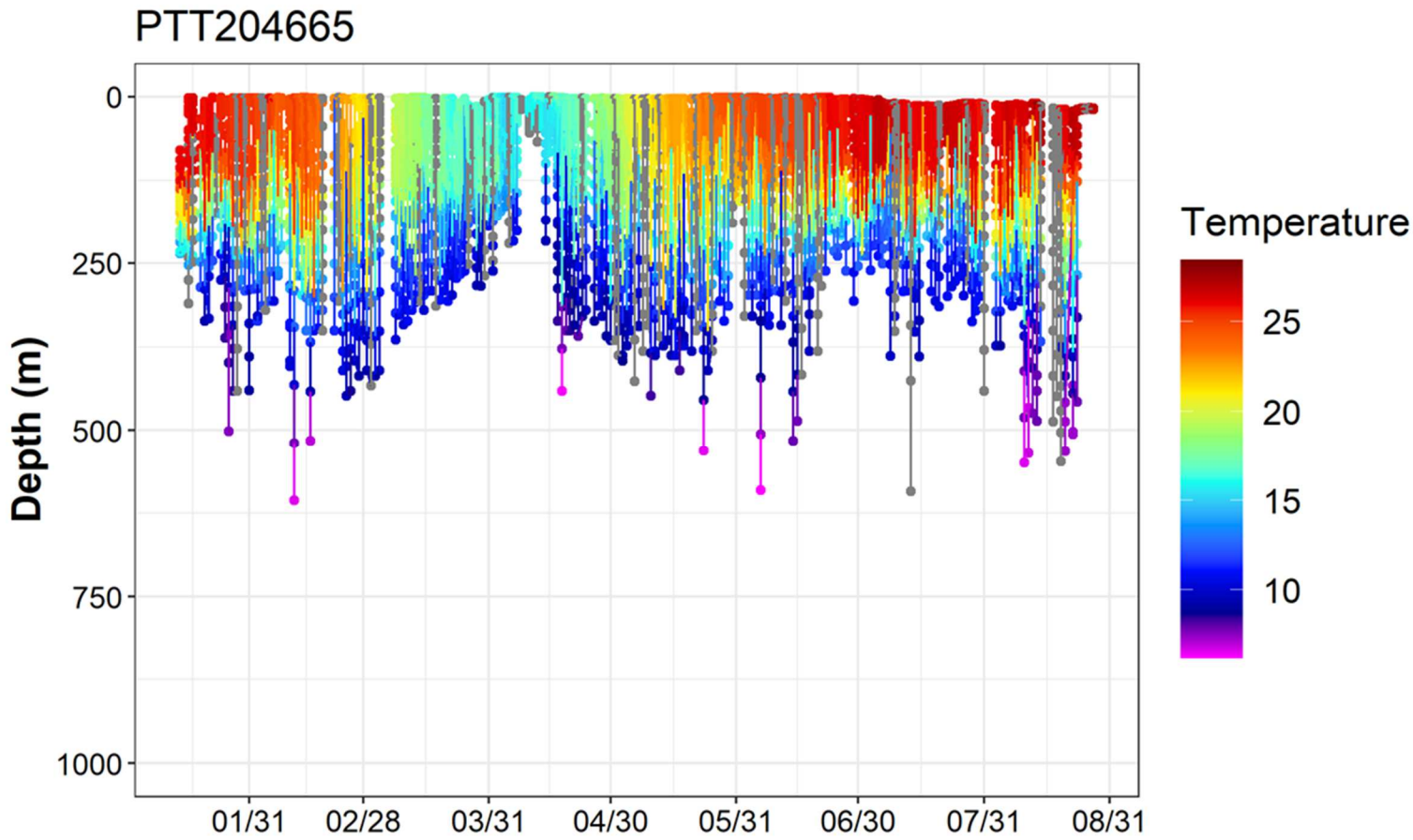

Figure 3. Time series of depth and experienced temperature of tagged female blue shark (#204665).