Novel use of pop-up satellite archival telemetry in sawsharks: insights into the movement of the common sawshark Pristiophorus cirratus (Pristiophoridae)

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Research

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Abstract

Background

Understanding movement patterns of a species is vital for optimising conservation and management strategies. This information is often difficult to obtain in the marine realm for species that regularly occur at depth. The common sawshark (*Pristiophorus cirratus*) is a small, benthic associated elasmobranch species that occurs from shallow to deep-sea environments. No information is known regarding its movement ecology. Despite this, *P. cirrata* are still regularly landed as nontargeted catch in the south eastern Australian trawl fisheries. Three individuals were tagged with pop-up satellite archival tags (PSATs) off the coast of Tasmania, Australia, to test the viability of satellite tagging on these small elasmobranchs and to provide novel insights into their movement.

Results

Tags were successfully retained for up to three weeks, but movement results differed on an individual basis. All three individuals displayed a post-release response to tagging and limited vertical movement was observed for up to 5–7 days post-tagging. Temperature loggers on the tags suggest the animals were not stationary but moved horizontally during this time, presumably in a flight response. After this response, continuous wavelet transformations identified diel vertical movements in one individual at cyclical intervals of 12- and 24-hour periods, however, two others did not display as clear a pattern. Temperature was not significantly correlated with movement in the study period. The deepest depths recorded during the deployments for all individuals was approximately 120 meters and the shallowest was 5 meters.

Conclusions

This study demonstrates that sawsharks can be successfully tagged by pop-up satellite archival tags. The data presented here show that sawsharks regularly move both horizontally and vertically in the water column, which was an unexpected result for this small benthic species. Additional research aimed at resolving the trophic ecology will help identify the drivers of these movements and help to better define the ecological, behavioural and physiological roles of these sharks in their ecosystems. These data describe a substantial ability to move in the common sawshark that was previously unknown and provides the first account of movement ecology on the family of sawsharks: Pristiophoridae.

Background

Organisms in the deep-sea biome present various environmental challenges for study even with the most technologically advanced equipment (1). Despite a lack of biological information for many deep-sea inhabitants, habitat within the deep-sea biome are increasingly targeted for harvest by expanding fisheries (2, 3). Deep-sea sharks (species that predominantly occur below 200 meters) remain one of the more poorly understood group of elasmobranchs but are regularly caught in fisheries (4, 5). In areas where deep-sea sharks are targeted, dramatic population declines have been observed (5, 6). The impacts of harvesting such species are usually unknown but may have long lasting consequences because of the low productivity and low intrinsic rebound potential observed in many deep-sea chondrichthyans (4).

Sharks play a crucial role in ecosystem functioning and stability (7–9). Many species perform critical roles in structuring biological communities through predation by exhibiting top-down controls thus allowing lower trophic levels to maintain viable diversity (10, 11). As such, the presence, abundance and health of such predators have been used as indicators of the overall health of ecosystems (10, 12, 13). In addition, indirect effects of predators can be observed through prey response to the predators (14). Such effects involve prey actively avoiding certain areas or habitats associated with sharks or high shark abundance (14, 15). These result in increased time and energy spent on predator avoidance, which could impact the fitness of prey species (16). Consequently, these effects substantially influence species and communities throughout the predator's distribution.

Sawsharks (Pristiophoridae) share many of the typical characteristics of deep-sea sharks and are also relatively understudied (4, 17). Most of the information known about this group is derived from fisheries-dependent sources (18–22). These data often lack location of fishing grounds, species-specific information for nontarget catch, and inherent bias introduced by a commercially driven fleet (23). As such, the true demographics and population structure of these animals are generally unknown (4). This is problematic as many populations are continually fished. Undoubtedly, fisheries management needs a broad understanding of species-specific information to make informed decisions on management strategies (24).

The common sawshark *Pristiophorus cirratus* (Latham, 1794) is a small, benthic-associated shark endemic to south eastern Australia and occurs from shallow to deep-sea environments (25). Very little information is known about this species and what is known is primarily from recent studies relating to aspects of their diet (26) and biological features (27, 28). These animals are a regular facet of nontarget catch in the trawl fisheries of south eastern Australia (19) and despite over 90 years of continued fishing there remains a dearth of biological data on *P. cirratus*, particularly in movement ecology.

Understanding animal movement is key if meaningful management and conservation efforts are to be effectively employed (29). The scope of an animal's ability to disperse influences population dynamics, nutrient distribution, productivity, resilience and other ecosystem level processes (30). For example, the first marine protected area located entirely in the high seas was partially justified by movements of the Adélie penguins (*Pygoscelis adeliae*) during their energy-intensive premoult period (31). Furthermore, many human activities pose serious threats to the ecology of marine life (32, 33). Examples include increased fishing pressure (34, 35), pollution (36, 37) and oil and gas extraction or exploration (38, 39). Knowledge of movement patterns can provide data essential for the identification and mitigation of potential impacts (30). Until recently, collecting this information for small deep-sea sharks was very challenging (40). However, miniaturization of satellite telemetry tags and their ability to record location and abiotic factors has made such data collection more feasible for these species, including smaller-bodied sharks (40). In this study, we tested the efficacy of pop-up satellite archival tags on the common sawshark as an initial assessment into the applicability of using such tags for tracking movement of smaller deep-sea sharks, and to assess short-term movement in relation to depth for this sawshark species. This study provides the first baseline data on movement ecology from satellite tagging for any Pristiophorid species.

Results

Three PSATs were deployed and all three sawsharks swam away strongly on release. Tag retention durations were 14 days (Tags 167263 and 167264) and 23 days (Tag 167262) (Table 1). The percent of archived data successfully transmitted to the ARGOS satellite network was 64% for tag 167262 and 93% for tag 167264. Tag 167263 was recovered, allowing the entire uncompressed dataset to be downloaded. Date and location of first transmission paired with corresponding depth profiles and bathymetry were used to indicate a rough path of movement (Fig. 3). Geolocation was not assessed as tags 167262 and 167263 failed to record several light levels, making implementation and interpretation of these data points unreliable. As an HR tag, 167264 was not able to provide geolocation.

Table 1
Pop-up satellite archival tag retention and deployment data for three common sawsharks.

Tag #	Tag Type	Total length (cm)	Sex	Deployed	Start Lat (N)	Start Long (W)	Popoff Date	Retention Time (Days)	End Lat (N)	End Long (W)
167262	SR	106	M	12/6/2016	-41.017	148.255	12/29/2016	23	-41.637	148.498
167263	SR	102	M	12/6/2016	-40.997	148.334	12/20/2016	14	-41.377	148.312
167264	HR	110	M	12/6/2016	-40.999	148.344	12/20/2016	14	-43.094	148.412

Tag 167262

Archived data from the sawshark bridled with tag 167262 suggested a post-release period of limited vertical activity for approximately five days. Variability in the temperature data suggested that the shark was not stationary after release but most likely moved in a horizontal plane (Fig. 2a). After approximately five days the shark continued moving towards deeper water but began to exhibit vertical movement events, some of which were up to half the depth of the water column (Fig. 2b). Mean depth of the shark's position differed significantly between day and night ($F_{(1,529)} = 42.42$, $p = 1.71e{-10}$; Fig. 2c). Through the use of continuous wavelet transformations CWTs, diel patterns of movement were identified in a cyclical pattern of approximate 12- and 24-hour periods (Fig. 5a). Cyclic patterns were discerned through high amplitude bands or peaks in red with statistically significant patterns encircled in white ($p < 0.1$) and black lines representing periods of the strongest statistical patterns ($p < 0.05$). Archived depth data paired with timing of first received transmission from the ARGOS network were used to describe a conservative minimum horizontal movement of approximately 70 kms from tagging to release in the 23-day deployment period.

Tag 167263

Data from the sawshark bridled with tag 167263 displayed similar post-release activity to the individual supporting tag 167262. Vertical movement of the shark with tag 167263 was limited for five days post deployment, but after this the shark started making regular vertical forays (Fig. 3a). Most of the vertical movements during this time occurred at night (Fig. 3b). Mean daily depth was significantly different between day and night ($F_{(1,347)} = 15.39$, $p = 0.0001$; Fig. 3c). CWTs identified cyclical patterns in the middle of the deployment at approximately 12- and 24-hour periods (Fig. 5b). Cyclic patterns are discerned through high amplitude bands or peaks in red with statistically significant patterns encircled in white ($p < 0.1$) and black lines representing periods of the strongest statistical patterns ($p < 0.05$). This individual displayed one vertical anomaly as it made a rapid ascent to approximately 5 meters before returning to 70 m depth across a period of about 11 min (Fig. 3b). Following this event, the tag then reported multiple days of limited vertical movement before the tag was shed. While this tag was recovered around St. Helens, Tasmania (-43.377, 148.312), substantial error in data recording and a lack of recording for several key time periods prevented meaningful estimation of horizontal movement or geolocation. Deployment location to recover location was approximately 60 kms.

Tag 167264

Archived data from the sawshark bridled with tag 167264 displayed a more variable post release activity pattern than those of the other individuals. Mean daily depth was not significantly different between day and night ($F_{(1,172)} = 1.122$, $p = 0.291$; Fig. 4c). Similarly, this animal appeared to head towards deeper water but resumed vertical movements earlier than individual 167262. On initiation of vertical movements, the shark displayed a 'yo-yo' pattern (41) where it made continuous ascents and descents with no apparent temporal influence or cyclical pattern for approximately two days (Figs. 4 & 5c). Approximately five days post release, tagged shark 167264 displayed a near constant depth profile until the tag released (Fig. 4a) and this, paired with archived temperature data, may suggest a mortality event. Archived data showed that the tag was separate from the animal and on the surface of the ocean for two weeks before successfully transmitting to the ARGOS satellite network, making an accurate estimation of distance travelled problematic.

Discussion

This study provided the first insights into the movement ecology and novel use of pop-up satellite archival tags in any member of the sawshark family. While the low sample size represented in this study limits our conclusions on a broader scale, it provides evidence for previously undescribed vertical behaviour of the common sawshark and more importantly, the applicability of PSAT technology in sawsharks.

The common sawshark *Pristiophorus cirratus* displayed a considerable ability to move. The first transmission date of the tags when paired with archived tag data allowed us to ascertain a conservative distance of animal movement over time. This track displayed a minimum movement of 70 kms in three weeks, or 3 km day^{-1} in one individual. Previous research on other small benthic sharks, such as the Port Jackson shark *Heterodontus portusjacksoni*, found rates of movement around 1.8 km day^{-1} (42) and 6.5 km day^{-1} (43). Furthermore, a recent study investigating long-term migrations of Port Jackson sharks found that they can move up to 19.5 km day^{-1} and move distances greater than 600 km in migratory events (44). Therefore, future research into sawsharks should aim to monitor individuals for evidence of philopatry or migratory events with a longer-term tracking study.

Diel vertical movement is a common phenomenon observed across a broad range of marine taxa (45–52). A number of shark species display diel vertical movements correlated to ascension at night and a return to depth at day (53–57). Our data suggest that sawsharks may employ a similar pattern of movement. One of our tagged individuals displayed regular vertical movements in the water column by ascending during the night in approximately 12- and 24-hour cyclical patterns and returning to what we assume is the sea floor at night. Similar diel movements were observed in another individual. However, the third individual displayed a very different vertical pattern of movement. Diel mediated vertical movement patterns are common in large epipelagic fishes (50, 51), however, this phenomena is not well documented in small, benthic-associated fishes (45). Current literature suggests the common sawshark feeds primarily on benthic primary consumers (26), so it is plausible the observed vertical movements are predatory events following the well documented diel movements of primary consumers (58–60). Furthermore, similar ‘yo-yo’ vertical movements where the animal makes regular rapid vertical ascents then descents have been linked in other shark species for prey detection (51). Our present dataset, however, is lacking the resolution required to unequivocally link a driving factor for such movement and should be a focus of future research for sawsharks.

The impacts of sawsharks employing vertical movements may have greater implications for the movement of nutrients across their distribution. Research has shown that predators are capable of rapidly altering nutrient cycling rates through direct excretion and through nutrient translocation (61). The consistency of ascension to five meters depth by of one of our tagged individuals suggests that common sawsharks may move from richer, shallower coastal shelf waters to the deeper continental slope benthos may play an important role in nutrient cycling of these ecosystems (61, 62). Clearly it is difficult to make too many assumptions on such a limited dataset and more tagging is required to understand the importance of this behaviour to the ecology of this species, sawsharks and their respective ecosystems.

The behavioural changes observed in our tagged individuals post-release suggested a potential impact of the tagging event on the behaviour on sawsharks. All three individuals displayed limited vertical movement during this period and a progressive movement towards deeper water, potentially as a post-release response to capture. Presumably, this could be a defence mechanism where moving to deeper waters may provide increased protection against visual predators potentially due to lower light levels (50, 63). This response may also be related to behavioural, physiological and biochemical changes such as those observed in a range of species in relation to capture induced stress (64–67). These include blood chemistry parameters such as lactate or pH, which have been correlated to irregular behaviour and even to moribund fish (48, 68, 69). Furthermore, these effects have been observed to have lasting sublethal effects that may affect the fitness of released fish

(65, 66). Capture induced stress and subsequent effects are species specific and likely mediated by basic biological functions, allowing for better adaptions to capture (i.e. buccal pumping allowing for oxygenation when movement is limited by fishing gear). However, it is still unclear what effect fishing has on the physiology on sawsharks and their resilience to capture and subsequent release. Areas of future study could include monitoring and comparison of blood physiology parameters under different fishing techniques to allow a better understanding of technique specific responses, which could then allow for better understanding of survivability post-release.

It is possible that one of our sharks perished during the monitored period. Mortality events are an inherent risk of studying sharks that first must be captured for tags to be fitted. One study estimated that sawsharks in the gillnet fisheries have an approximate 50% mortality rate post-release, thought to be due to physical damage received in the gillnet (70). Mitigation of capture stress to promote survivability of fish post tagging has seen increasing attention (40, 71). Novel techniques such as releasing tagged sharks in cages where the door is pressure released on reaching the seabed has seen some success by providing animals shelter while they recover (40). However, our current understanding of sawshark biology and ecology is lacking the fundamental information to understand what the main drivers of stress and eventual mortality in released sawsharks are.

Conclusions

Consistent decreases in sawshark landings across all south eastern Australian fisheries have recently been observed (19). With only eclectic information on the biology or ecology of sawsharks, the impacts of increased fishing pressure in deeper waters remains unknown for these species. Contemporary literature has called for research into their movement and genetics to better understand population structure and, therefore, resilience to fishing pressure locally and at a species level. Though the data in this study is limited to three individuals, this pilot study lends insight into previously unknown sawshark movement and serves as a model to build on for future sawshark telemetry studies. Due to the limited replication and temporal scope of this study, broad conclusions on sawshark movement cannot be conclusively made. Our data provide documentation, however, of considerable water column use and an undescribed diel vertical movement of the species. Given these data presented here, we suggest that more comprehensive tagging studies are warranted to better understand the ecology of these poorly understood sharks.

Methods

Sawsharks were caught and tagged off the northeast coast of Tasmania, Australia (40.99 S, 148. 33 E) during a research cruise in December 2016 on the FTV Bluefin. A series of short, deep trawls between 60 m and 100 m using a 70 mm mesh demersal fish net were conducted for 30 min at a speed of approximately 3.1 knots (kn, 1 knot = ~ 0.5144 m s^{-1}) in an effort to reduce stress on the sharks by reducing the time spent in the net. Common sawsharks (n = 3) were tagged with two types of pop-up satellite archival tags (PSATs): X-Tags (Standard Rate [SR, n = 2] and High Rate [HR, n = 1], Microwave Telemetry, Inc., Columbia, MD, USA) (Table 1).

Data on temperature, pressure (depth), and light levels (geolocation) throughout the preprogramed deployment period were collected by the X-Tags. Due to satellite throughput limitations, entire datasets are not automatically transmitted by the tag. Instead, a smaller subset, the ‘transmitted’ dataset, generated by a series of compressions applied to the archived dataset is sent to the satellites, depending on tag deployment programming chosen. In our research, the two SR tags compressed and transmitted data in 15 min records while the HR tag compressed and transmitted data in 5 min records.

On capture, individuals were measured (total length, TL) to the nearest centimetre, sexed, assessed for health and immediately tagged with a pop-up satellite archival tag (PSAT) to the dorsal fin via a bridal method. Only healthy individuals with no sign of capture damage or exhaustion were used and the study was limited to males to eliminate any sex-specific movement. The bridal method involved piercing a small hole at the base of the dorsal fin then threading through a 10 cm length of monofilament attached to the PSAT and securing via a crimp. This method has been successful in securing similar tags in a range of other sharks and was advised by the tag manufacturers (40).

Tagged individuals were placed in a holding tank (1 m x 2.5 m x 0.75 m) on the deck of the vessel to recover and then released. Recovery was identified as when an individual was swimming normally irrespective of the tag (Williamson, personal observation). As retention time of the tags on sawsharks was unknown, each of the three tags was programmed to compress data at different time internals to maximise the opportunity of ecologically important data retrieval. PSATs were thus programmed to release at 30 [HR tag 167264], 60 and 90 [SR tags 167262, 167263] days, respectively.

Data Analysis

All tag data were explored, plotted, and analysed using R Studio (ver. 3.3.0, R Foundation for Statistical Computing, Vienna, Austria) and ArcGIS (ESRI, ArcMap 10.6). Data were binned hourly, standardised for sunrise and sunset and then delineated into day (6:00–20:59) and night (21:00–5:59) based on natural diel patterns of deployment duration. Data on daily mean depth of day and night positions were analysed using ANOVAs.

Periodicity in vertical movements were investigated using Continuous Wavelet Transformations (CWTs). CWTs (Morlet wavelet) identify dominant cyclical signals in time series datasets and display a frequency of how they change through time (72). In essence, CWTs are capable of interpreting multi-scale, non-stationary time series data and reveal features we may not see otherwise (73). The mean depths for each hour of the entire deployment were determined and CWTs were produced on these data using a Morlet wavelet in the waveletComp package (74) in R Studio. CWTs were calculated using the following parameters: loess span = 0, dt = 1, dj = 1/250, lowerPeriod = 1, upperPeriod = 64, n.sim = 100, see Roesch and Schmidbauer (2014) for a full description of these parameters (75).

Declarations

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Research was conducted under the approval of the Macquarie University Animal Ethics Committee, approval number ARA 2017_060 and the University of Tasmania Animal Ethics Committee, approval number A0015366, in collaboration with the University of Newcastle.

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Authors’ contributions

PJB wrote the manuscript and created figures, PJB and JM analysed the data, JEW and JM participated in the at-sea operations, JEW designed the study, all authors contributed to writing, revising and approving the final manuscript.

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Figures

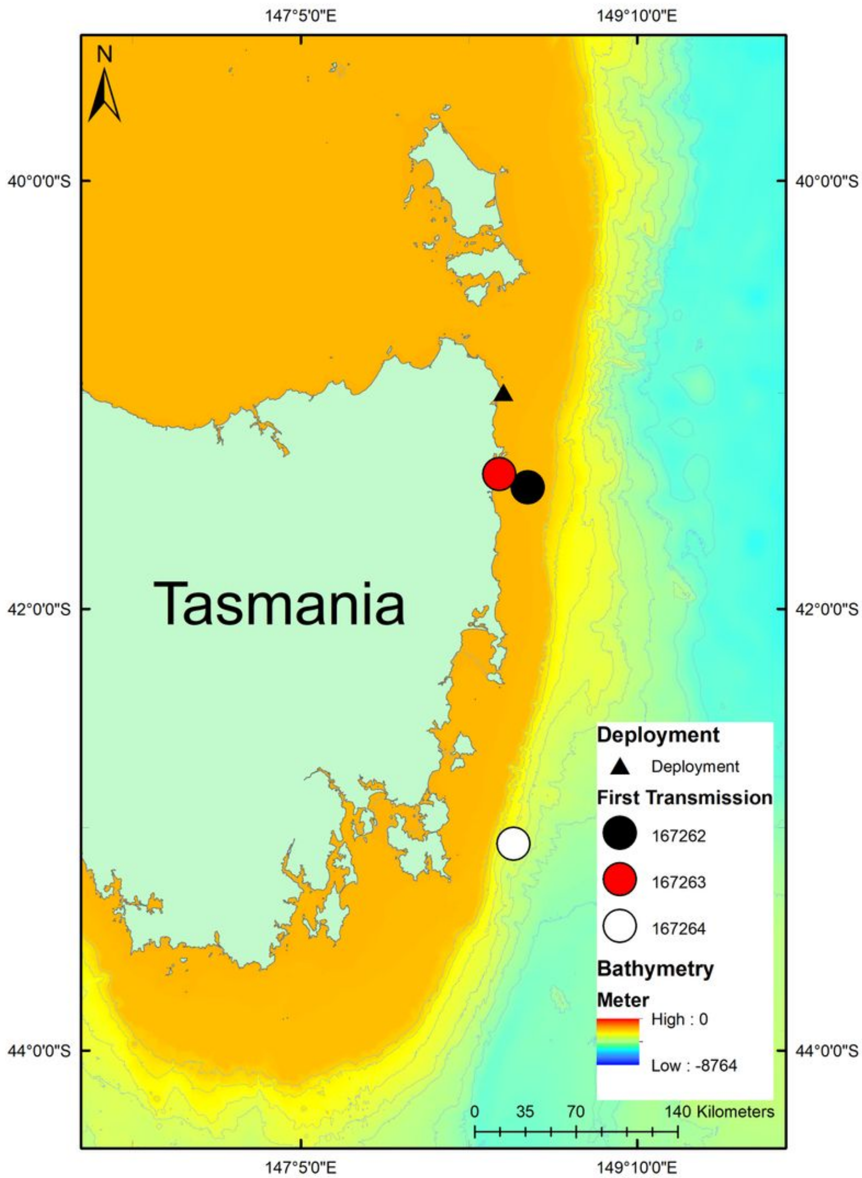


Figure 1

Bathymetric map depicting the tagging location (black triangle) and initial satellite transmission locations (circles). Note that pop-up transmission locations may have occurred after variable drift times.

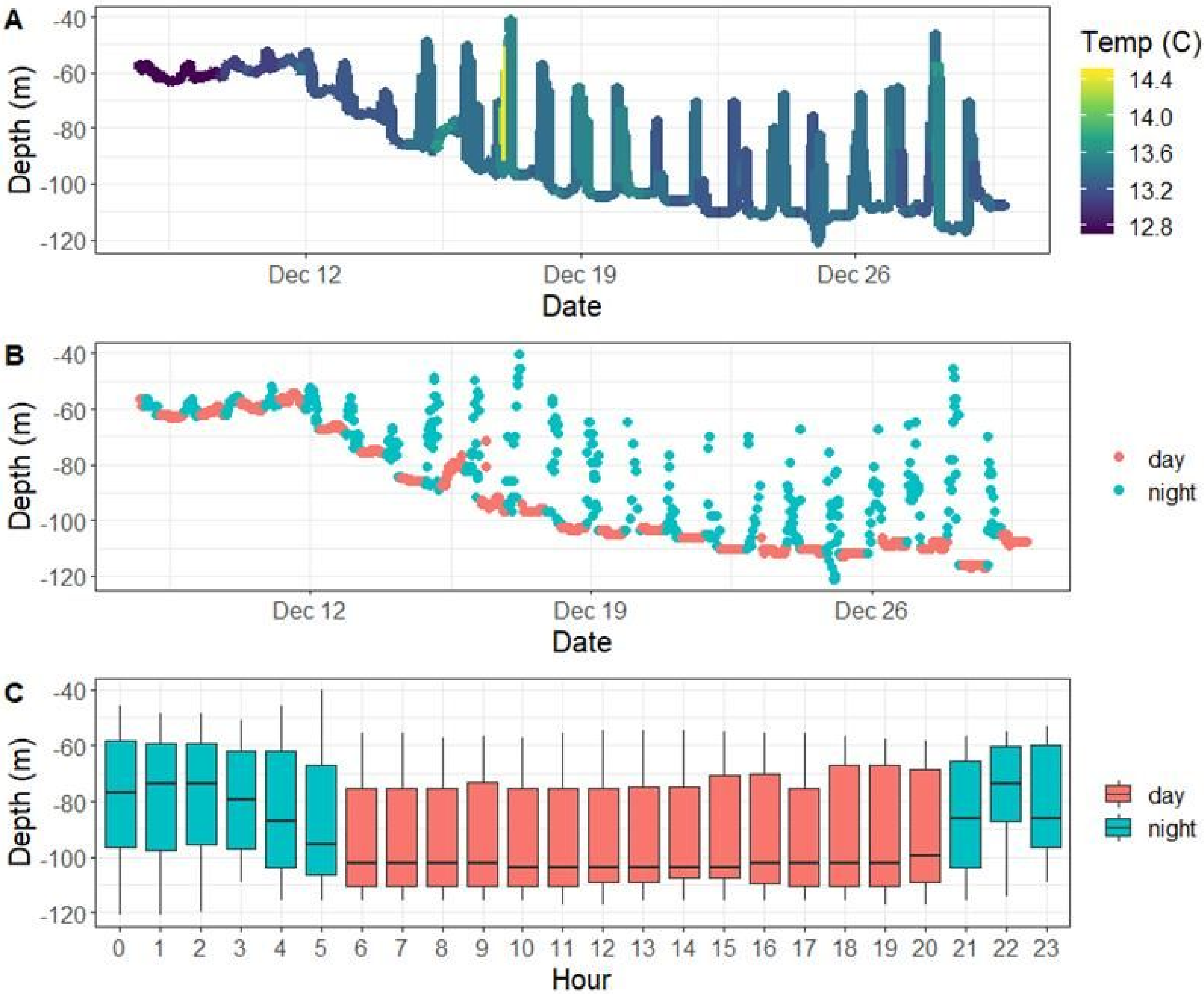


Figure 2

Depth profile of a common sawshark using a pop-up satellite archival tag (Tag ID: 167262). A) Ambient temperature recorded across depth. B) Vertical movements in relation to time of day. C) Median depth through hours of the day of a common sawshark

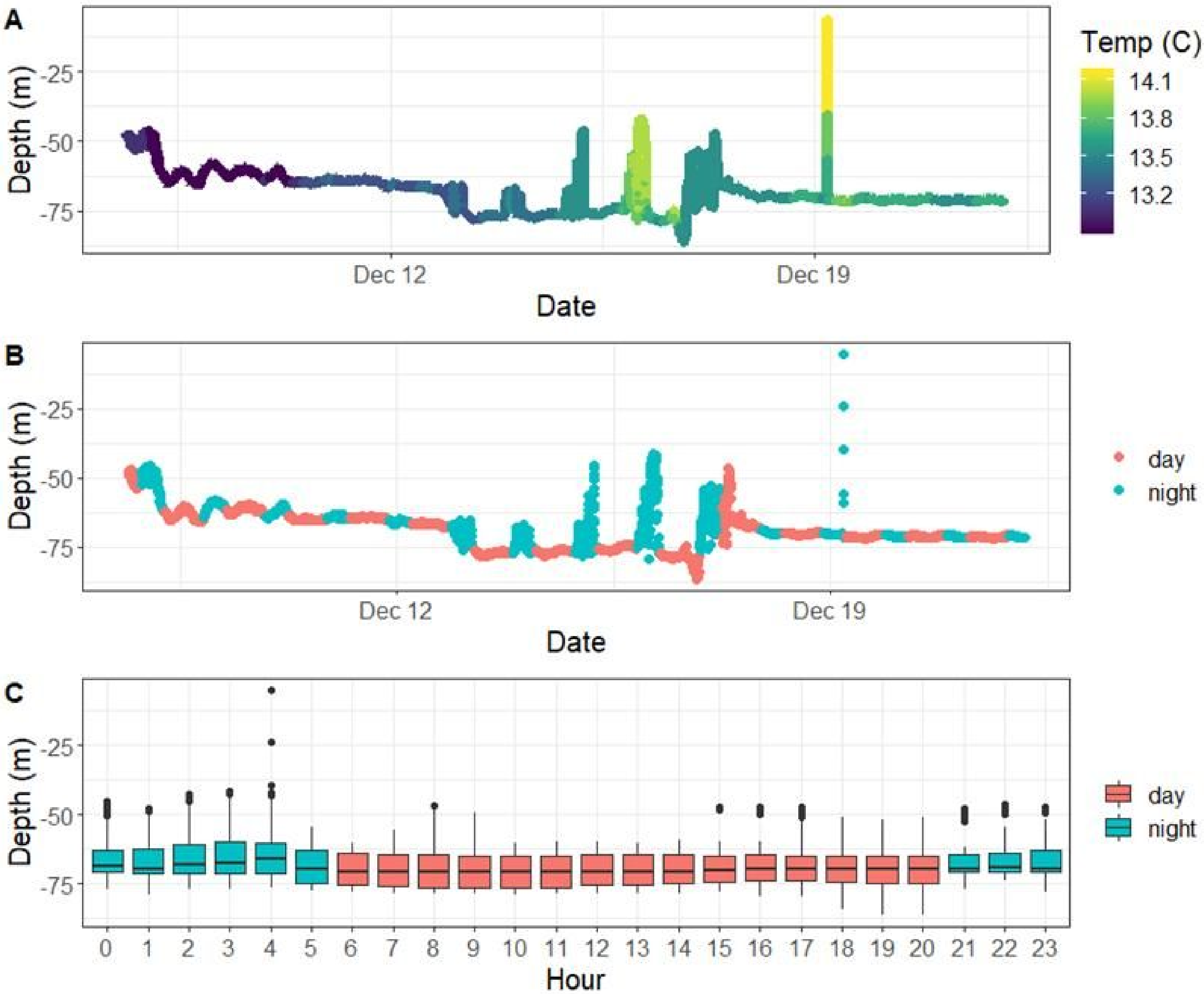


Figure 3

Depth profile of a common sawshark using a pop-up satellite archival tag (Tag ID: 167263). A) Ambient temperature recorded across depth. B) Vertical movements in relation to time of day. C) Median depth through hours of the day of a common sawshark

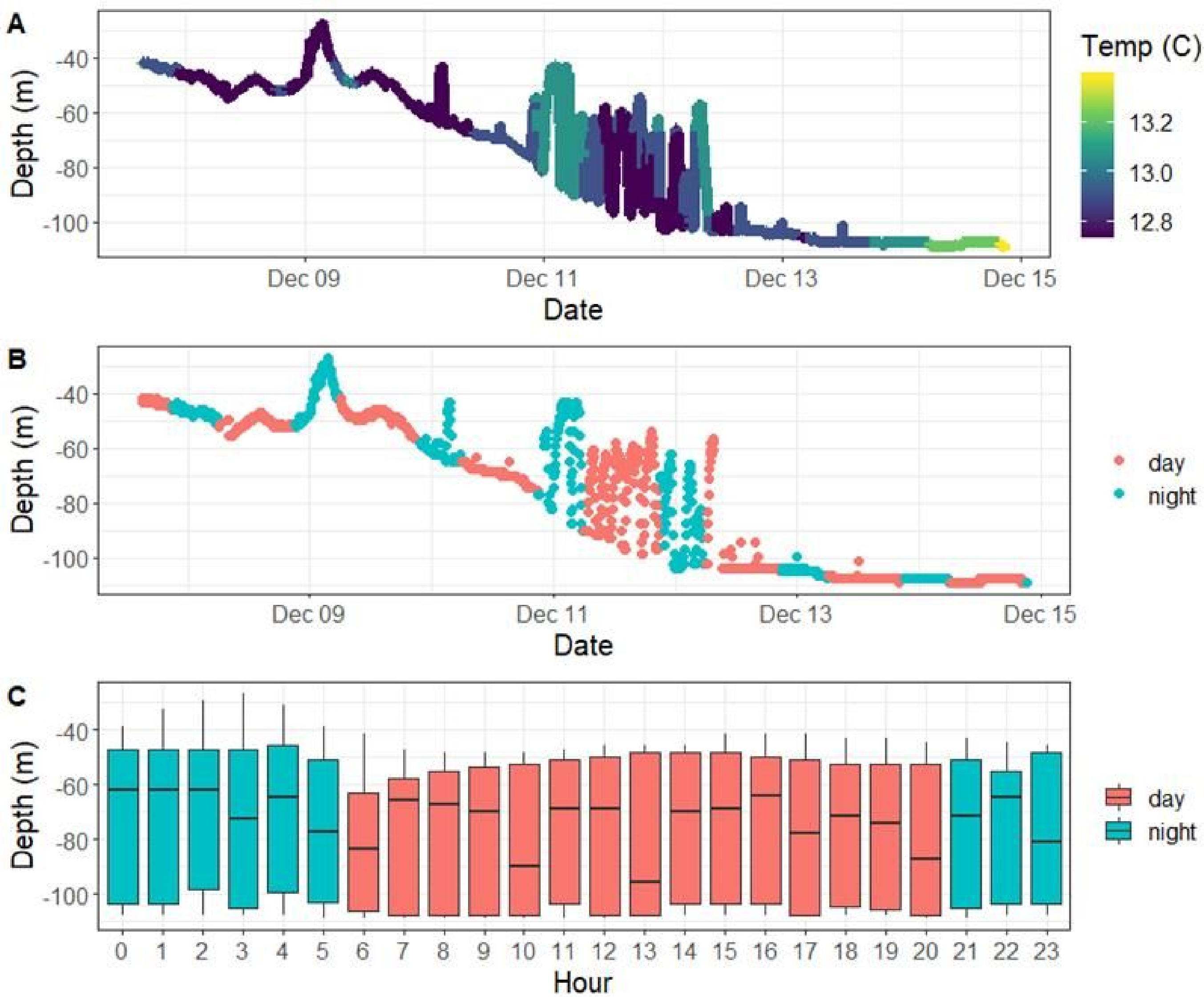
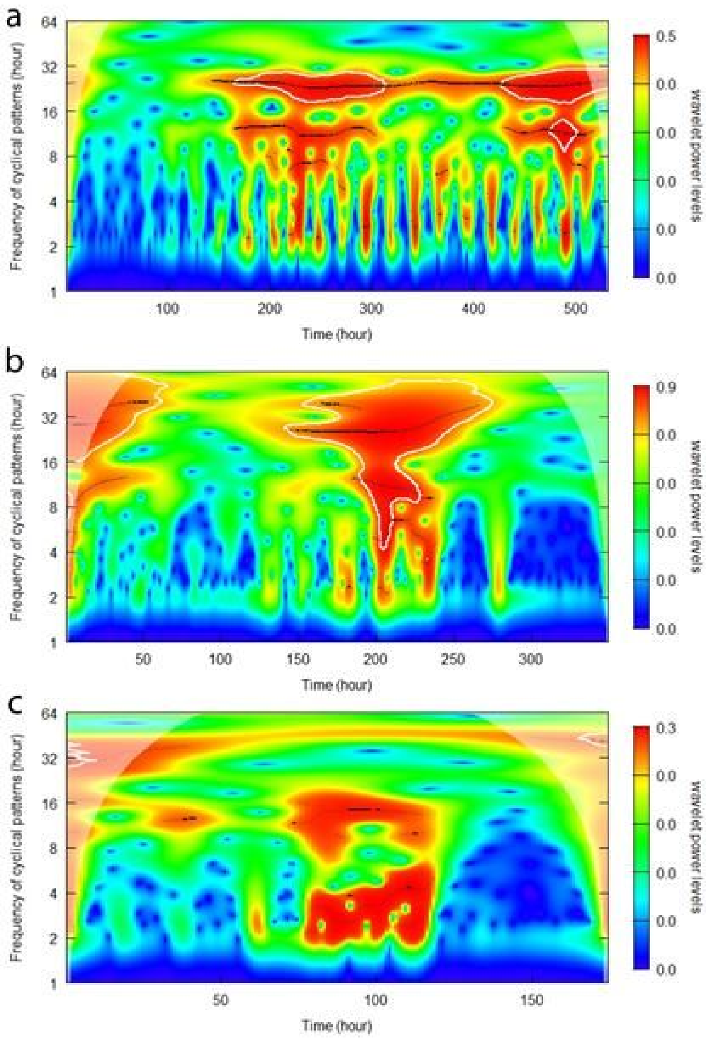


Figure 4

Depth profile of a common sawshark using a pop-up satellite archival tag (Tag ID: 167264). A) Ambient temperature recorded across depth. B) Vertical movements in relation to time of day. C) Median depth through hours of the day of a common sawshark



LIst 2

Figure 5

Continuous wavelet transformations (CWTs) for vertical movement of three sawsharks tagged with PSATs a) tag 167262, b) tag 167263, c) tag 167264. The x-axis represents total hours post tagging and the y-axis shows frequency of cyclical patterns in hours. Patterns outside the cone of influence should not be interpreted. Areas circled with white lines represent statistically significant patterns of periodicity of vertical movements at a significance of $p < 0.1$ and the black lines represent statistically significant patterns of periodicity of vertical movements at $p < 0.05$. Wavelet power levels indicate the strength of patterns observed across the period analyzed.