Project Title: **Increasing the quality and resolution of data from the fishery using satellite popup tag technology: Characterizing the fine-scale habitat positioning of sablefish in the water column and tracking movements during spawning**

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Background

Sablefish (*Anoplopoma fimbria*) have a wide distribution along the Pacific coast, extending from Baja California to Alaska, the Bering Sea and through to the eastern coast of Japan. While the landed weight of sablefish in the commercial fishery is relatively small, the exceptionally high value of this species ranks it 3rd in economic value to other U.S. groundfish (Sonu, 2014). As such, sablefish are highly managed throughout the Pacific, and understanding the biology of this species is essential for proper management.

Given the wide distribution of sablefish, potentially crossing various management regions, the movement of this species has been of paramount interest and addressed in a number of past tagging studies (e.g., Echave et al., 2013; Heifetz and Fujioka, 1991; Beamish and McFarlane, 1988; NOAA Technical Report NMFS 130). However, the majority of the studies conducted so far provides information only on movements over broad ranges and do not provide information on the location of fish within the water column or movements at the time of spawning. The reason is that fish are tagged, released and recaptured only once by commercial or recreational fishers. This type of tagging provides start and end points with no details about depth or the hourly/daily/weekly movements of individual fish. Implanted archival tags provide information on the movement and depth of fish on a finer, individual and continuous time scale but still require recovery of the fish by commercial fishermen and do not provide information on location. In contrast a newer version of the archival tag is the "pop-up" satellite tag (PSAT). Pop-up satellite tags are composed of a data-logger and battery, and a float with attached antenna (Fig. 1). The tag is tethered to the fish and the data logger is programmed to continually collect depth, temperature, and location for a specified duration (weeks to months). At the end of the programmed time, a detachment mechanism is automatically activated that releases the data logger/float and antenna from the tether. The float carries the data logger to the surface where the antenna transmits the data to an orbiting satellite of the ARGOS System (http://www.argos-system.org/) that then transmits data back to the researcher.

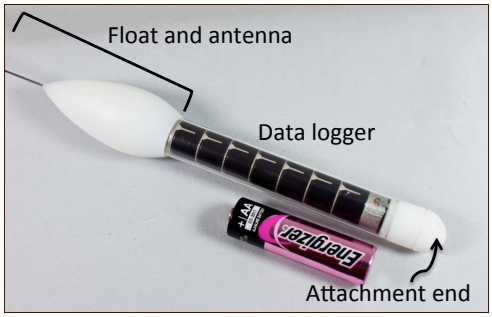

Figure 1: SeaTag MOD with data logger, float and antenna. Attachment end goes to tether and detachs from fish by explosive charge

For sablefish, two fundamental questions related to their movements are 1) Where do they go during spawning and 2) Are sablefish adults only benthic inhabitants? Both questions have implications for the assessment and management of this species. In this project, we used commercial fishermen (Eric Samuelson-*Playboy II*; Chuck Custer-*Freedom*) to obtain large (>6kg) female sablefish by longline from a site off the Washington coast and tagged these fish with PSATs and released them back to these sites. The tags have been programmed to detach after two (June-August) and six (November-April) months, and data obtained from these tags

were analyzed to determine the movements of the fish relative to depth/temperature and depth selection prior to, during and following the spawning period.

Results

Summer 2015 deployment: For a preliminary test deployment, five fish were collected by longline on June 15, 2015 at the Quinault Canyon (Figure 2) and tagged onboard with PSATs and released. These tags were programmed to release from the fish August 3, 2015. Of the five fish, three tags surfaced at the programmed time. The remaining two tags never reported. We relied on the ARGOS transmissions for these three tags since direction finding (DF) equipment was still being manufactured for actually locating and retrieving the tags from the ocean. Data that is obtained from the tags only through transmissions is limited since the tags only transmit data to satellites when they are overhead and, since power in the tags is derived from solar cells when conditions are good (sufficient light) for transmissions. Also, because of biofouling, the tags eventually cease transmitting to the satellite. Even so, we were able to obtain depth histogram data from the three tags in which the depth that a fish resided in four hour increments was transmitted. For one of these tags a nearly complete dataset over the two month deployment period was obtained (Figure 3). Unfortunately, the other data (temperature, light) archived in these tags was not obtained since it would require a significantly greater transmission time. That is why we focused on the development of DF equipment that could be used to actually locate and retrieve the tag in the ocean once they released from the fish. The manufacture of this equipment by RDF Products (Vancouver, WA) was complete by the end of summer, 2015 and was used successfully for tag retrieval following subsequent tag deployments (see below).

As we might have suspected, the results from these preliminary tags indicated that these sablefish spent a significant amount of time at great depths (e.g., 600 meters). However, what we did not expect was that they also appeared to migrate vertically towards the surface and at times this migration appeared to have a diurnal cyclicity (Figure 3-highlighted area).

Fall 2015 Deployments: We used the preliminary summer deployments to refine the harness techniques for tagging sablefish and also to obtain an idea of where tags might surface and how they moved once they were at the surface. In October 2015 (10/14/2015; 10/15/2015) we used a commercial fisherman to longline 20 sablefish (av. = 766.5 mm) at the same location on the Quinault Canyon as with the summer deployments (Figure 2). These fish were harnessed with PSATs and released within 1-2 miles of the collection area. The tags were programmed to release from the fish on April 3, 2016 (10 tags) and April 10, 2016 (10 tags). We planned to use commercial fisherman and a NOAA vessel (R/V Tatoosh) to locate and retrieve the tags using the DF equipment. Of the twenty tags, twelve surfaced. Some (six) of the tags surfaced prior to the programmed date and were followed by ARGOS but not retrieved due to weather conditions since they occurred during the winter. Of the remaining tags, six were on time or slightly delayed and of those we were able to locate and retrieve five of the tags. One tag stopped transmitting to the ARGOS system several days after surfacing and could not be located for retrieval. We found that if weather conditions permitted and boats were available, a tag could always be located and retrieved. Figure 4 summarizes the locations of tag deployments and surfacing ("popup") locations for all tags deployed in the summer and fall of 2015. Regardless of the overall movement along the coast, fish appeared to stay where the slope rapidly descended

and many of the tags released close to the deployment site. However, two fish migrated either north (Graham Island, Canada) or south (Oregon) from the deployment site (Figure 4).

From the tags that were physically retrieved, all of the data could be downloaded. This provided a very complete picture of the depth, temperature and light profile for four of the fish over the 6 month deployment. One of the five fish appears to have died approximately halfway through the deployment and that data is not presented. When looking at the depth/temperature plots of the fish it appears that the fish did go to fairly great depths extending to 800 meters. In fact several tags that surfaced prematurely transmitted an engineering code to ARGOS that indicated those fish had exceeded the crush depth of the tag (>1000 m) and thus had activated a premature release mechanism in the tag. Those tags were not retrieved since they surfaced in the winter so we are unable to determine the depth history of the fish prior to that release. While two of the fish (tags 1448; 1571) appeared to remain deep during the entire deployment (Figure 5), two of the fish (tags 1572; 1647) clearly underwent extensive vertical migrations towards the surface (Figure 6). These vertical migrations were within 10 meters of the surface but the temperatures clearly did not exceed 11^{o}C (Figure 6). In looking at the light (solar panel) recordings for those tags (e.g., 1572) it appeared that the fish did not migrate to the surface during the day, and when the day/night cycle was superimposed on the depth recordings, it was clear that nearly all migrations occurred at night (Figure 7). Further, magnification of these depth profiles revealed that during some nights the fish migrated up and down repeatedly at times over great distance (e.g., 400m Figure 7).

An objective of the fall deployments was to try and see what the depth profiles looked like during the spawning period. Since the spawning sites of sablefish are unknown we were interested to learn as much as possible from the tags during this period. At the time of tagging, we sexed the fish onboard using ultrasound and all of the fish for which we retrieved tags were females. Based on our prior reproductive life history analysis of sablefish off the Washington coast, it appears that the fish in these populations spawn sometime from January - February. When aligning the depth traces for the tags we retrieved during this time there was nothing that was particularly striking (i.e., depth or movement over depth) about the period from December 15-February 15 but we may need to tag a larger sample size to get a better picture.

Summer 2016 Deployments: We deployed a total of 25 tags on June 8 and 9, 2016 on sablefish (av. = 760 mm) collected by longline on a commercial fishing boat at the Quinault Canyon site (Figure 2) and these tags were programmed to surface on August 21, 2016. Of the 25 tags deployed, 20 surfaced (14 on time and 5 either later or early) and of those 20 tags, we physically retrieved 12 of the tags for full data recovery. This provided a very complete picture of the depth distribution of sablefish during the summer. We observed that most of the sablefish underwent vertical migrations (shallow at night and deep during the day) for some portion from June to August (e.g., Figure 8, fish 1577). This phenomenon is best illustrated by a time series, spectral analysis to determine periodicities in the depth selection activity of the fish (Figure 9). The more frequent the daily vertical migration, the higher the spectral density. From this analysis, several fish showed no spectral density at periods of 24 hours, but most demonstrated some 24 hour periodicity (note spectral density of fish 1577 shown in figure 8). This vertical migratory behavior can be defined as diel vertical migration (Brierley, 2014): daily migrations up and down in the water column, and most likely is a response of the sablefish to prey such as Pacific hake, cephalopods, or euphausiids.

Fall 2016 Deployments: In October (2016), 25 sablefish will be collected and tagged with PSATs that are programmed to surface in the first week of April, 2017 as we did in the fall of 2015. We are hoping to add to the data from the previous fall deployments and half of these tags also are recording data at a more frequent interval of one minute. The goal is to try and see if there is any fine-scale behavior during the winter that might indicate spawning. Until now, all data has been collected at four minute intervals and that may not be short enough to resolve spawning behavior. With our experience in using direction finding equipment, we hope to be able to recover a larger number of tags from the winter deployment.

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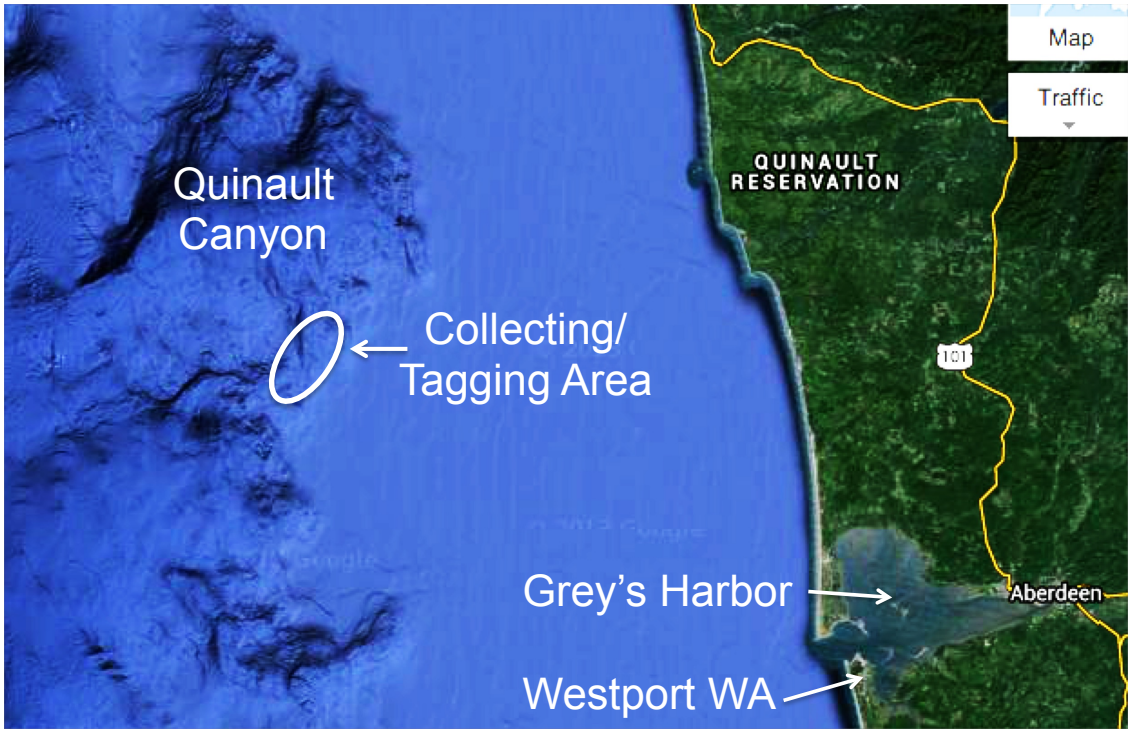
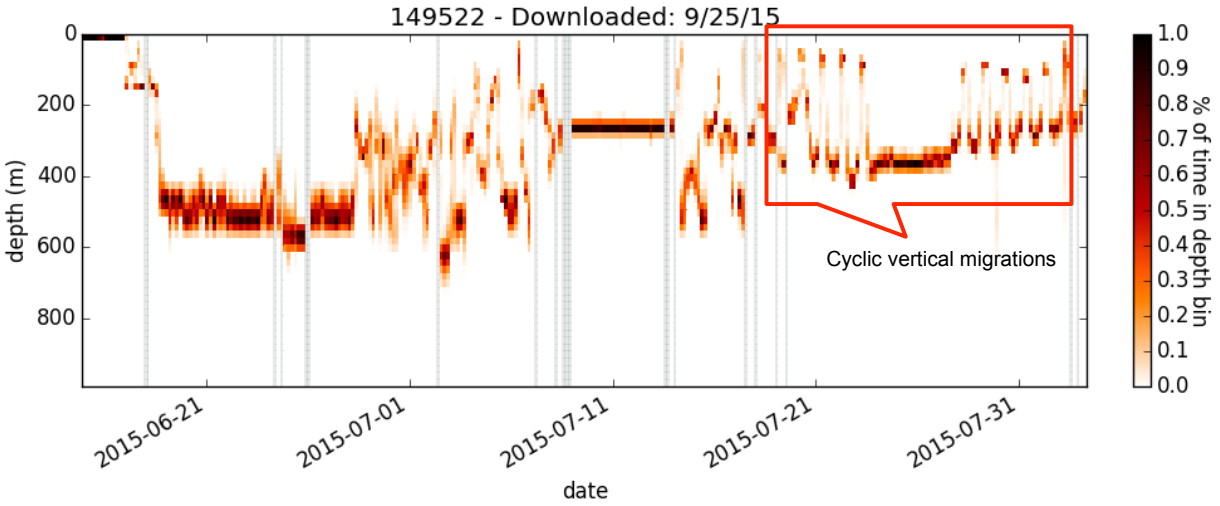


Figure 2: Map of the collecting and tag deployment area off the Washington coast

Figure 3: Depth histogram plot of a tag deployed on a sablefish in the summer for 2 months. Grey areas indicate data that was missing and not transmitted to the ARGOS satellite. Colored bars indicate % of time that the fish occupied a given depth within a 4 hour period (column). Note cyclic migratory behavior in the end of July, 2015.



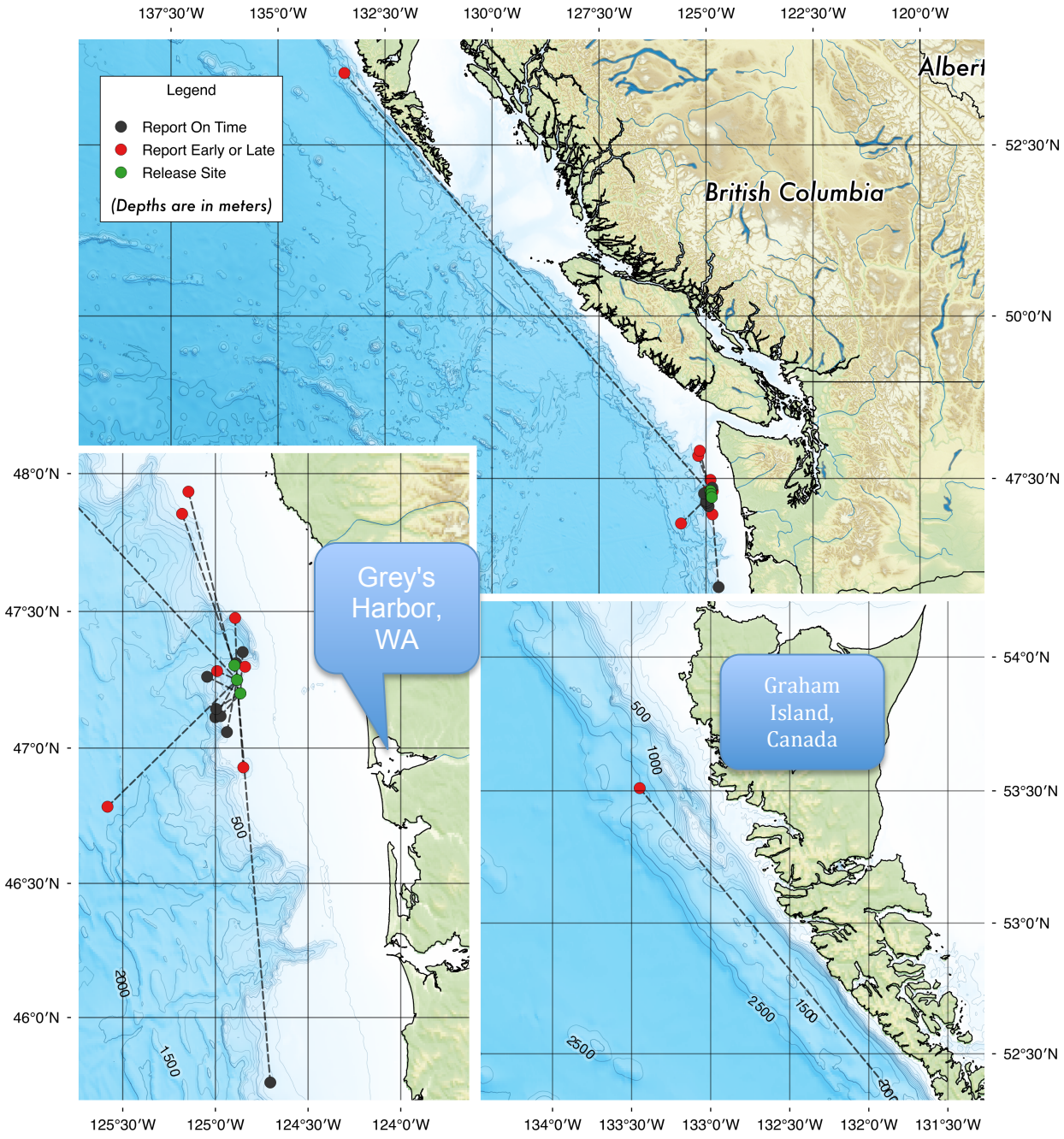


Figure 4: Locations off the west coast of all sablefish tag deployment sites (green) and individual tag popups (red - early or late; blue - on time) for tags deployed in the summer and fall of 2015.

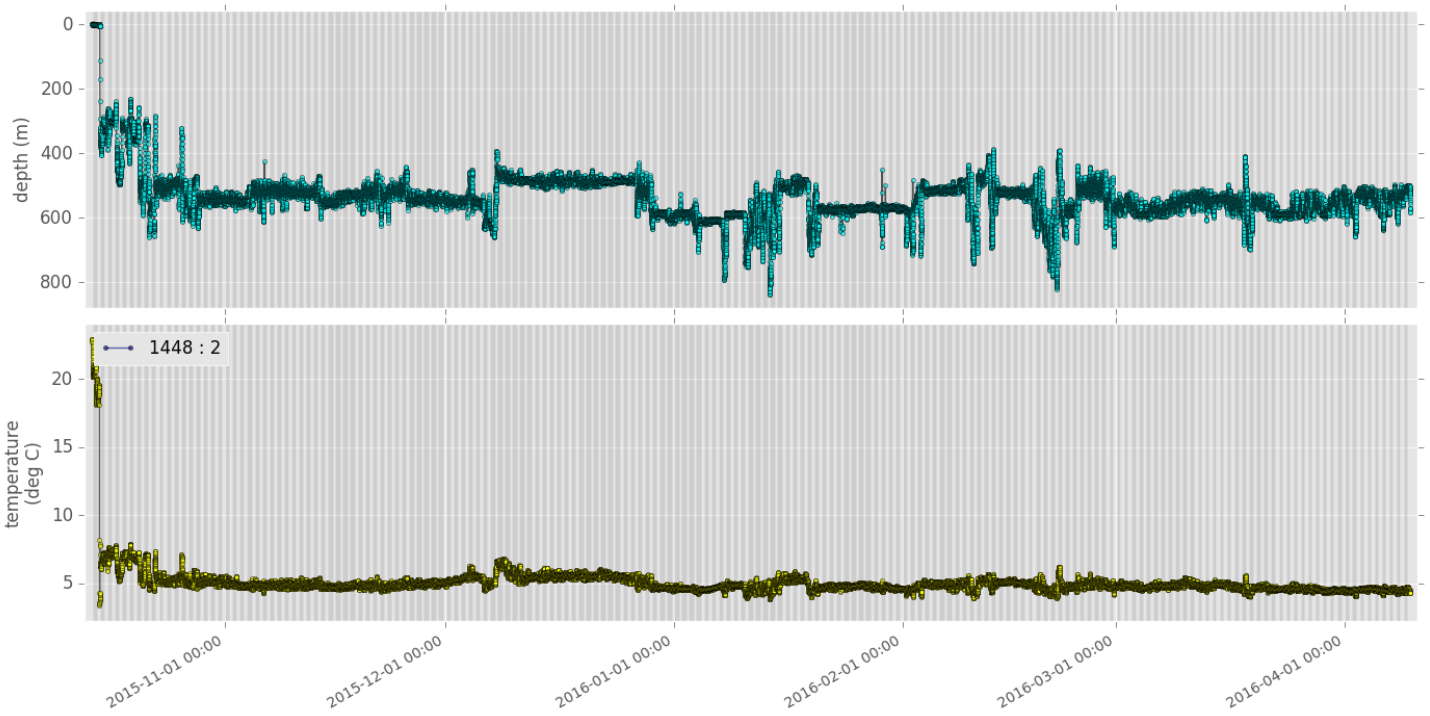
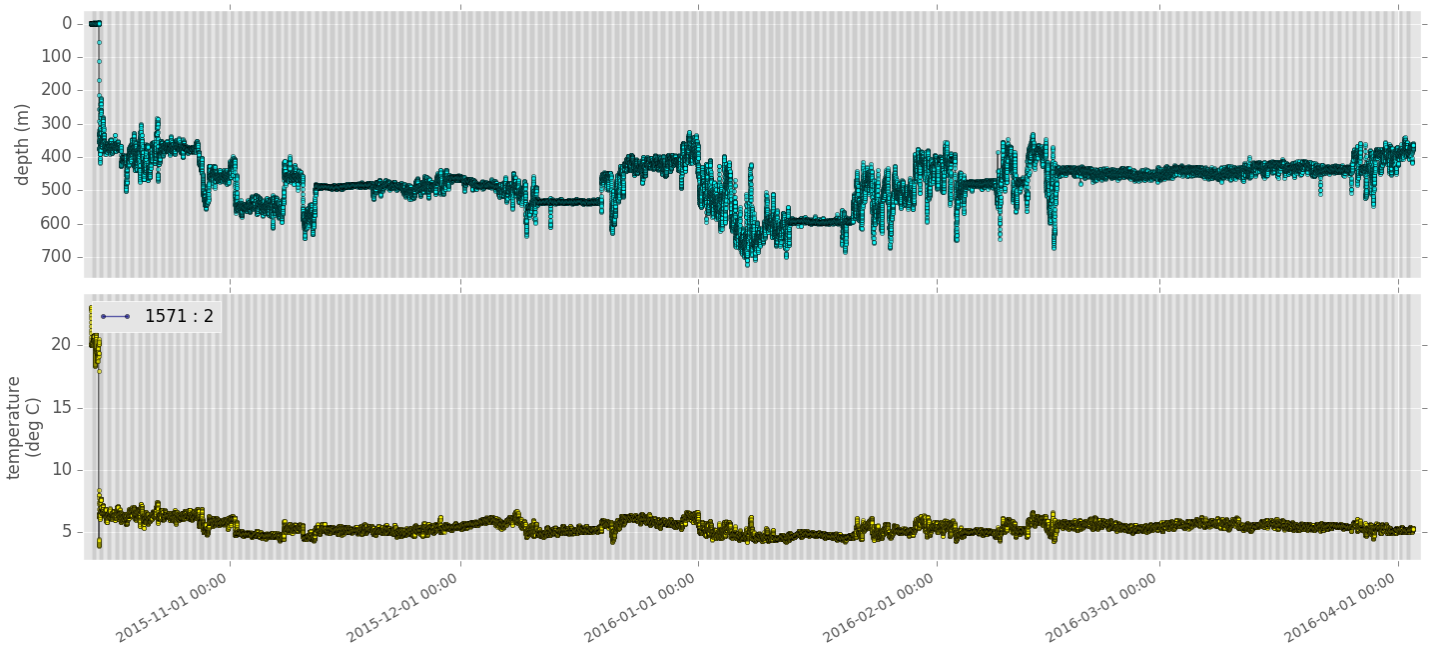


Figure 5: Depth and temperature profiles recorded every 4 minutes for tags 1448 (above) and 1571 (below), deployed on sablefish for 6 months from November, 2015 to April, 2016.



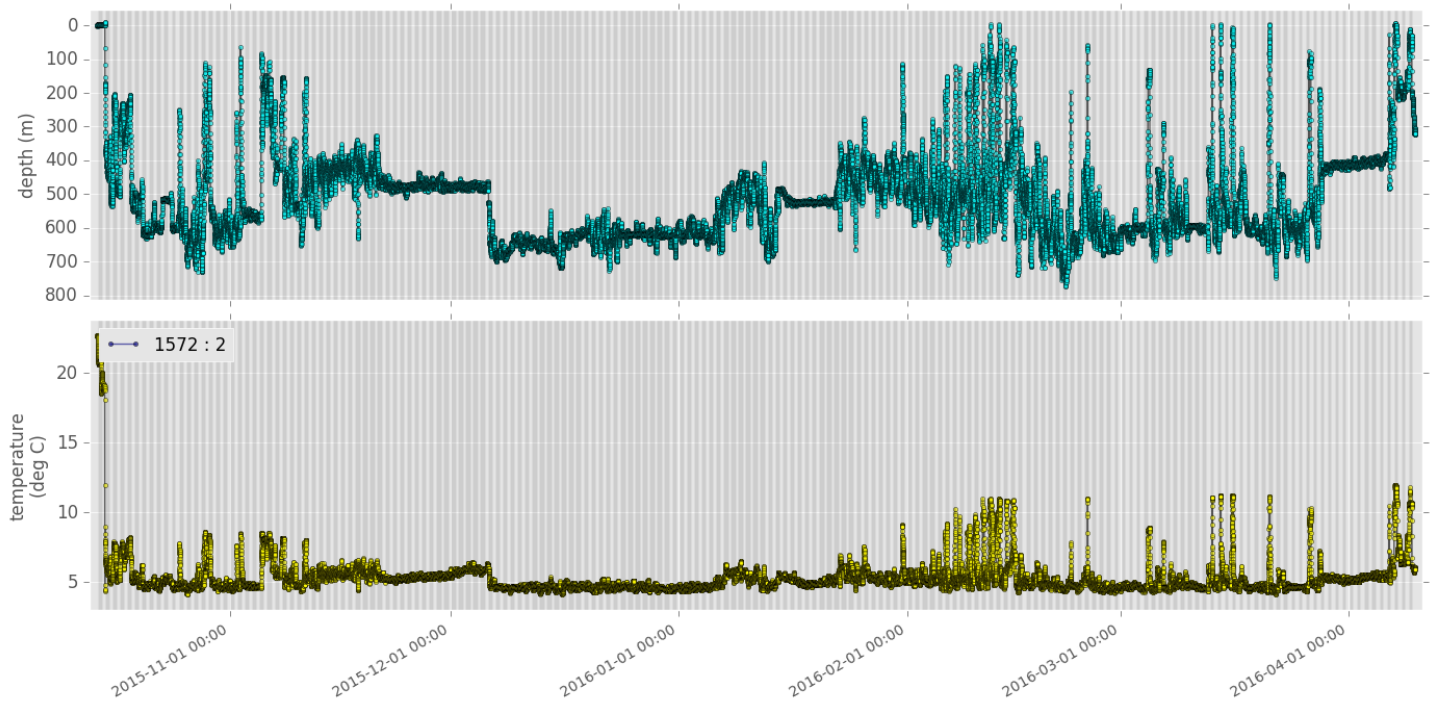


Figure 6: Depth and temperature profiles recorded every 4 minutes for tags 1572 (above) and 1647 (below), deployed on sablefish for 6 months from November, 2015 to April, 2016.

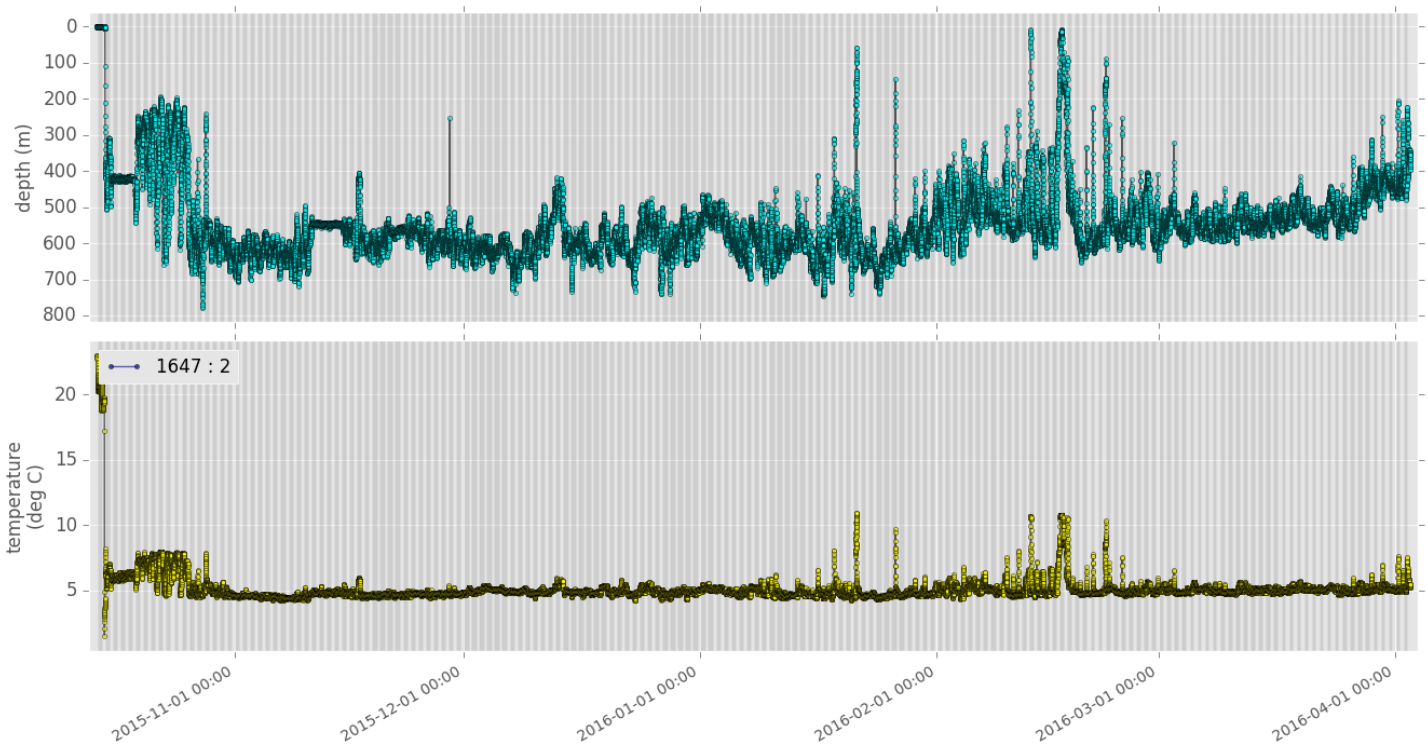
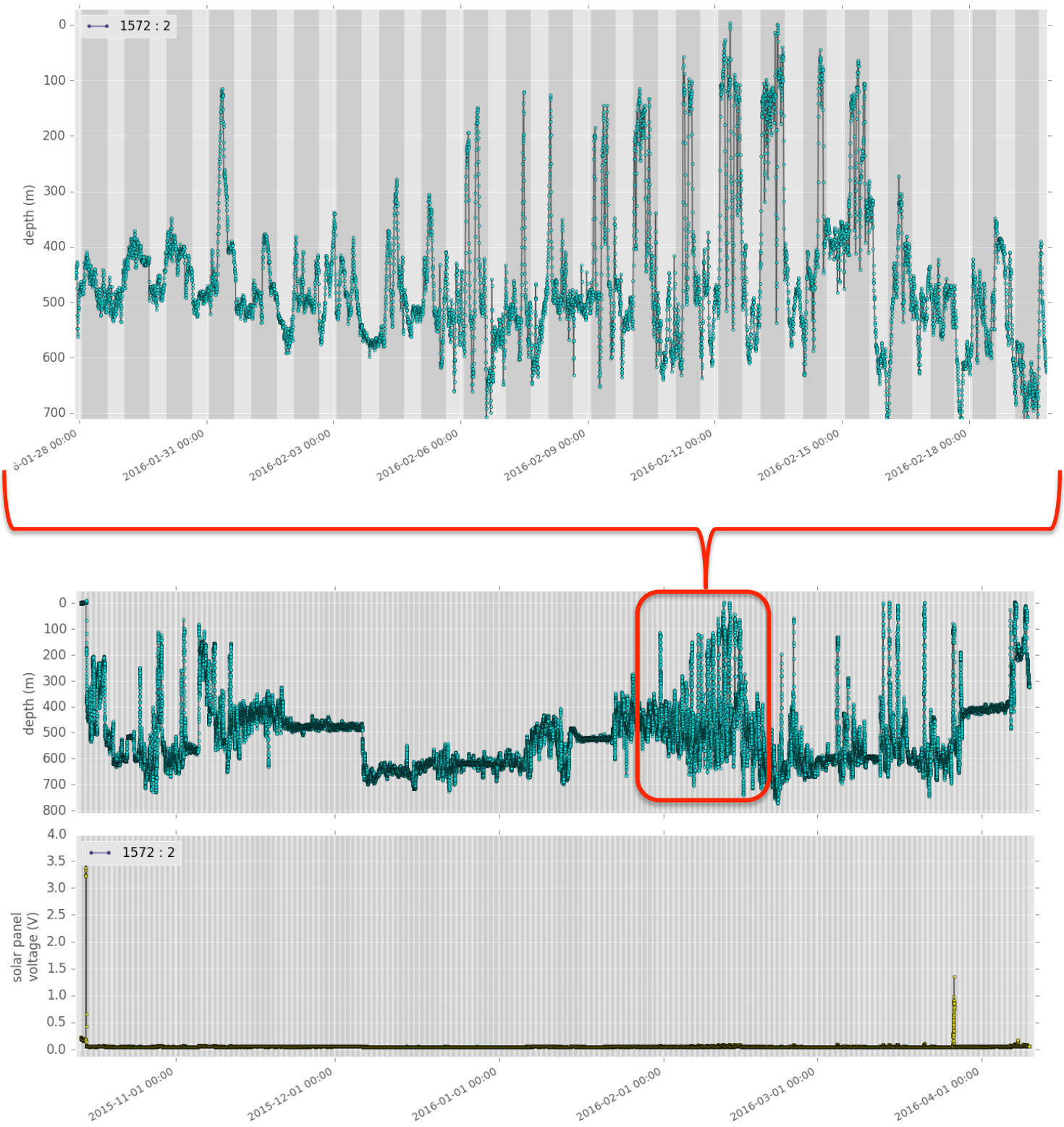


Figure 7: Bottom: Depth/light profiles taken every 4 minutes for fish 1572 tagged from November, 2015 to April, 2016. Top: Magnification of the depth profile for fish 1572 during one of the periods of extensive vertical migrations (see box in lower figure). Day/night cycle for that time of year are superimposed in the background with darker grey indicating night.



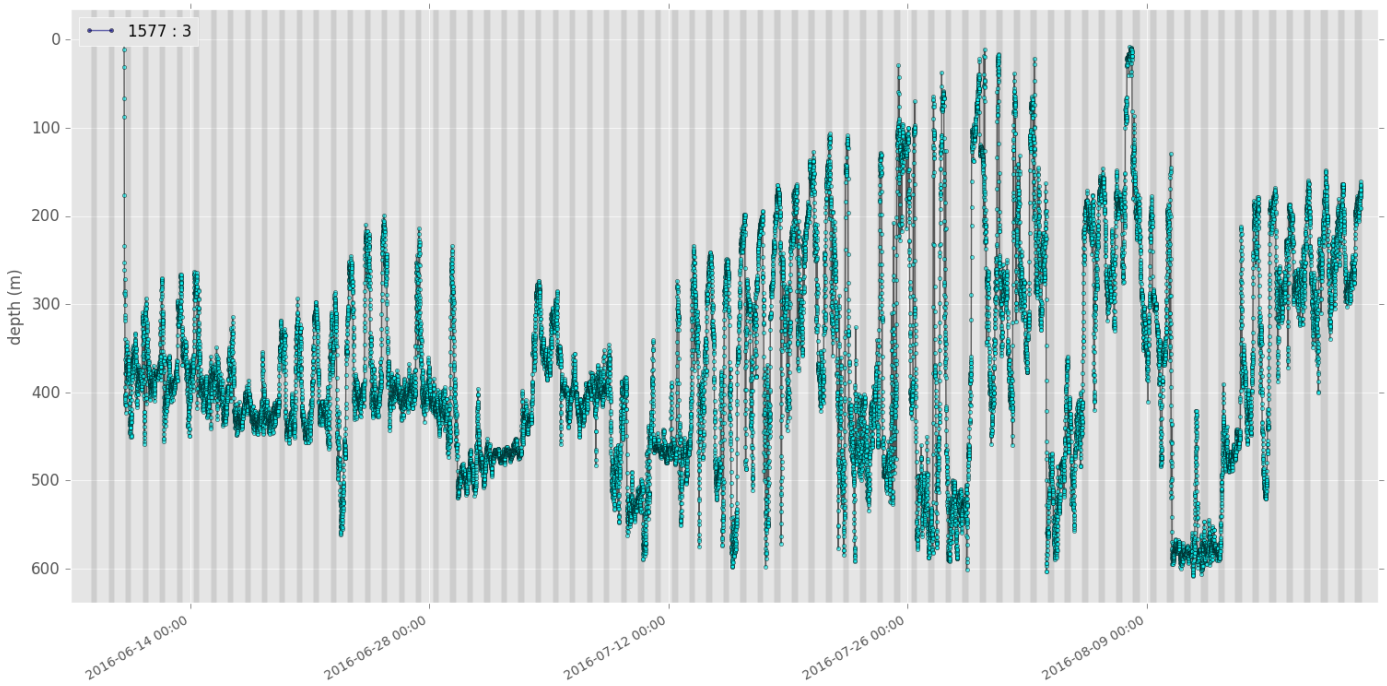


Figure 8: Depth profile taken every 4 minutes of Fish 1577 deployed for 2.5 months from June, 2016 to August, 2016. Note frequent vertical migrations occurring at night (dark shaded bars) as in Figure 7.

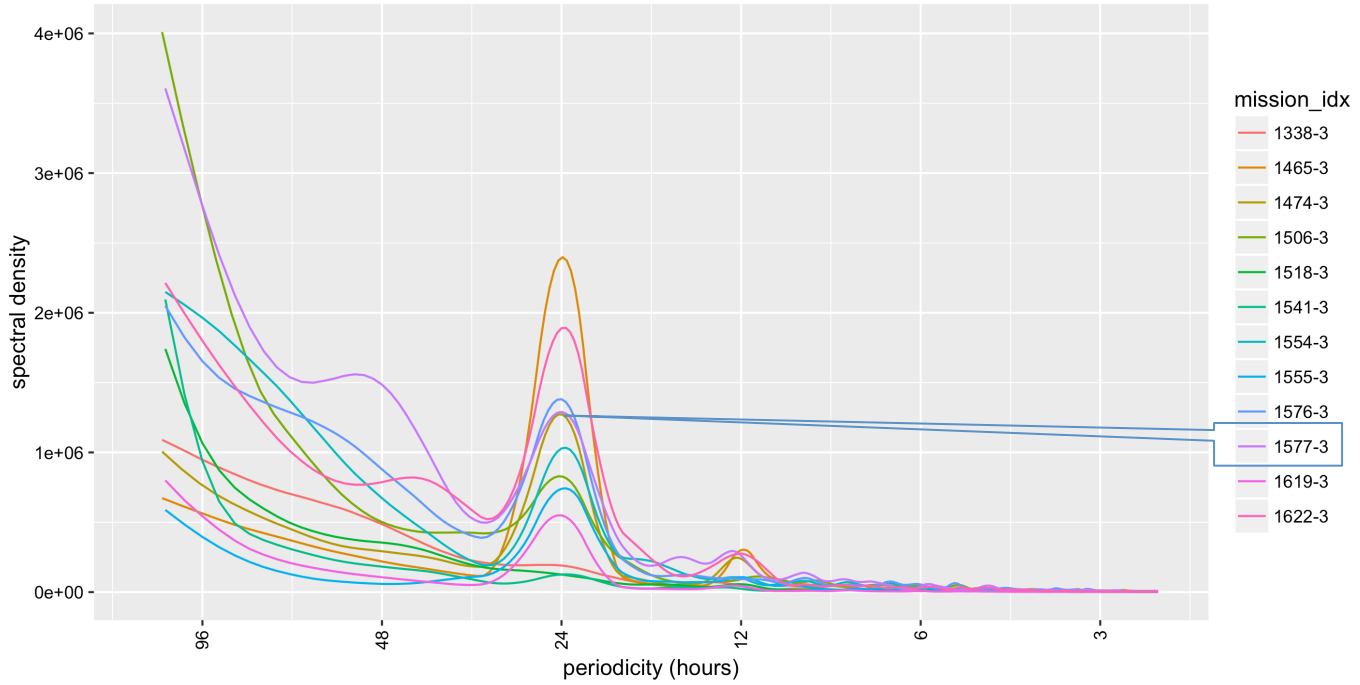


Figure 9: Spectral density analysis to determine periodicities in the depth profiles of 12 sablefish tagged from June, 2016 to August, 2016. Note strong 24 hour periodicities recorded in 9 of the 12 fish. Fish #1577 shown in figure 8 shows strong but still intermediate levels of periodicity compared with fish #1474.