FINAL REPORT

Deriving data for Northern Community Management of Arctic ecosystems: A mechanistic understanding of the residency, movement and large-scale migrations of high Arctic fish species under changing environmental conditions

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PROJECT:

Broad Scale High Arctic monitoring of residency, migration and vertical movement behaviours of Greenland sharks (Somniosus microcephalus) – technology and modeling advancement for satellite monitoring of Arctic fish species (2014-2016).

PLUS FINAL UPDATE ON WWF project (2013-2014)

Understanding the movement and behavior of a vulnerable by-catch species, Greenland Shark in the high Arctic

The Greenland shark (*Somniosus microcephalus*) – a 3.0 m total length male captured, tagged and released as part of this multi-year long term scientific monitoring program.

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BACKGROUND

As a species of interest in arctic ecosystems, the Greenland Shark (*Somniosus microcephalus*) is unique among marine fishes due to its large size, up to 7 m, and its role as a top predator in the polar environment; marine mammals are a common item found in stomach contents. Historical catch records from the Canadian Arctic and North Atlantic, and our own experiences with fishing for these sharks, suggest an abundance of Greenland shark however, little is known about their life-history. Given increasing fishing interests in the Arctic and concerns about high levels of by-catch of Greenland shark in trial commercial fisheries, the reported slow growth rate and population recovery of this species, rapid decline of many shark populations in temperate waters, and unprecedented change in Arctic ecosystems, there is a need to understand the general biology of this important but little known apex predator (Brendal et al. 2013; Figures 1 and 2). In particular, there is an immediate need to understand the daily and seasonal

Figure 1: Greenland shark (*Somniosus microcephalus*) caught as bycatch in Greenland halibut test commercial fisheries in Cumberland Sound, Eastern Canadian Arctic in 2011.

movement patterns and habitat preferences of juvenile to mature Greenland sharks in conjunction with the movement patterns of important prey items including commercial fish species, Greenland halibut and marine mammals; narwhal and beluga. Moreover, data on depth preference and related interactions with fisheries gear and overall general distribution of Greenland sharks is limited. Such information is critical for the development of the Arctic and North Atlantic management and conservation plan that can protect this large shark, and its ecosystem, in the face of mounting pressure to develop arctic fisheries and exploit natural resources (e.g. oil and fisheries; Figures 1 and 2).

Figure 2: Greenland sharks (*Somniosus microcephalus*) caught as bycatch during community longline fishing in Scott Inlet (Clyde River community)

For Arctic fish species, monitoring horizontal movements and migrations using satellite telemetry is typically complicated by the depth of occurrence of animals and Arctic light conditions and sea-surface temperatures that restrict current temperate/tropical modeling algorithms to refine location accuracies. Advancing quantitative methods to improve horizontal location modeling from satellite data is therefore of importance for future fish telemetry work in the Arctic environment. Current new technology is available for testing, which could provide the opportunities to advance modeling efforts to address these methodological constraints.

OVERALL PROJECT OBJECTIVES:

(1) To elucidate broad scale movements/residency patterns of Greenland sharks throughout the Arctic arena using both acoustic (long-term monitoring) and satellite (short term monitoring) telemetry. These data are being coupled with ongoing genetics work;

(2) Relate vertical and horizontal movement behaviours to prey base movements with a specific focus on marine mammal movements/migrations;

(3) To determine depth/temperature preferences to assess vulnerability to various artisanal and commercial fishing gears.

WWF SPECIFIC PROJECT OBJECTIVES:

(1) To expand the monitoring of Greenland shark movement behaviours to the little known high arctic region;

(2) To undertake the first scientific fishing for Greenland sharks in Griese Fjord, Jones Sound and acoustic/satellite tag individuals to examine regional high Arctic movement behaviours at the most northerly Canadian community. Tagging will be undertaken at the same time as satellite tagging of narwhal to facilitate direct shark-mammal movement-interactions;

(3) To trial new mark-report satellite locator tags in conjunction with standard pop-off archival satellite tags to provide additional location data that can be used to generate/validate bathymetric horizontal location correction models to improve the application of satellite telemetry technology.

METHODS:

To achieve the above objectives, (i) **Wildlife computer miniPAT pop off archival** and **Wildlife computer mrPAT satellite tags** and (ii) **V16-6H acoustic tags** will be externally attached and surgical implanted in Greenland sharks, respectively.

<u>Wildlife computer miniPAT pop off archival satellite tags</u> are attached externally to the fish using an anchor system that is embedded in the dorsal muscle tissue. This tag records temperature and depth at pre-programmed time intervals (time series data), and after a fixed amount of time the tags release from the animal, floats to the surface, and uploads information via communication with satellites. These tags can be programmed to remain on the shark for up to one year (Fig. 3).

<u>Wildlife computer mrPAT satellite tags</u> are externally attached to the fish in a combined attachment with the above archival tag (see first design for this dual tagging approach tested below). This tag is preprogrammed to release from the animal and provides a GPS location for where the tag surfaces. These tags are currently under development (they are not commercially available) and are designed for deployments on animals that inhabit deep waters where light level data is typically not available for reconstructing latitude/longitude locations (Fig. 3).

Figure 3: Wildlife computers miniPAT, mrPAT pop-off satellite tags and VEMCO V16-6H internal acoustic tag**.**

V16-6H acoustic tags are surgically implanted in the shark and send out a coded transmission that identifies individual fish to receivers placed in the Arctic and throughout the world (via the global OTN – www.oceantrackingnetwork.org). Since the acoustic tags will last 20 years (special agreement with VEMCO as tag life is normally 10 years), there is the potential to collect a significant time series of movement data on these long-lived fish over time through the network of established monitors (Fig. 3).

Sharks were caught using bottom set longlines with metal gangions baited with marine mammal bait (captured as part of Inuit local subsistence hunts), spaced every 5m along the baseline (between 5-10 gangions per set). Lines were hauled every 12 hours and any sharks captured processed next to the boat; length measurements, blood and tissue samples for ongoing chemical tracer food web work, fin clip for ongoing genetics work and electronic tagging (satellite and acoustic).

The aim of this first tagging work in Grise Fjord in conjunction with narwhal tagging work was to attach satellite and acoustic tags to five individual sharks (note the narwhal work in conjunction with members of the local community facilitated the field logistics for this project). In addition, we planned to equip three of these sharks with four additional mark-report satellite tags each. Consequently, for three individuals we will derive accurate GPS locations for the animal at four points prior to the main archival satellite tag popping off and transmitting the high-resolution depth-temperature time series data to satellite. This will enable the development and testing of bathymetric-satellite telemetry modeling to improve horizontal location accuracy for monitoring deep water Arctic fish.

PROGRESS ON PROJECT GOALS:

A: The Wildlife computer mrPAT tags were still under development and testing before being made commercially available. First test of this technology on Greenland sharks in the Arctic

It was expected that all field-testing of these new mrPAT tags would be complete prior to the scheduled fieldwork in Grise Fjord in 2014. Given this was not the case the team in conjunction with Wildlife computers elected to only deploy four individual tags on sharks to test their efficiency in this environment. The remaining budget for mrPAT tags was spent - we were able to purchase a total of 20 tags rather than the requested 12 given our collaborative work with the manufacturer. These tags are in frozen storage and will be used during the 2015 Grise field season.

As part of the testing, we field trialed the new online software program for the mrPAT tags (Wildlife TAG AGENT: http://wildlifecomputers.com). This highlighted several issues, particularly related to using the offline version of the software when in a remote location. Through close collaboration with Wildlife computers staff while in the field, several major problems were ironed out and the software has been modified accordingly.

B: First attachment design for multiple satellite tags including mrPATs

In conjunction with engineers at Wildlife computers the following multi satellite tag attachment rig was developed. This involved using stainless steel cable, stainless steel crimps and thimbles, with all wire coated with rubber insulation. The two tags were spaced to reduce collision and hence potential damage while attached to the animal (Fig. 4). The rig was attached to Greenland sharks using the new dorsal fin circular mount designed as part of the 2013-2014 WWF Greenland shark project (Fig. 5,6).

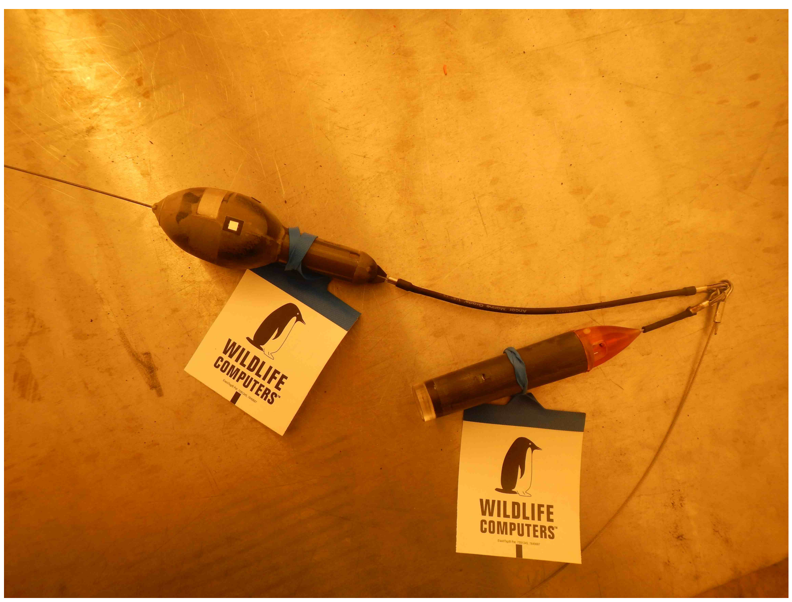

Figure 4: mrPAT and pop off archival satellite tag attachment design for trial on Greenland sharks in Grise Fjord.

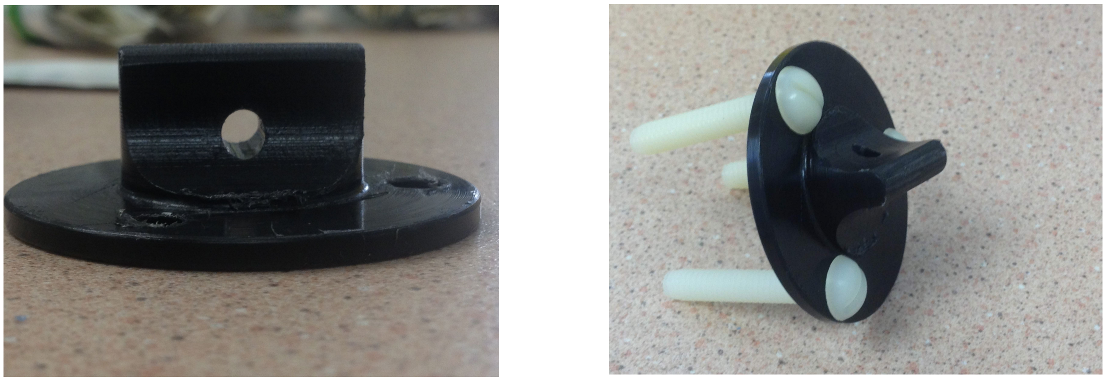

Figure 5: Circular disc satellite tag-mounting plate for attachment on Greenland shark dorsal fin.

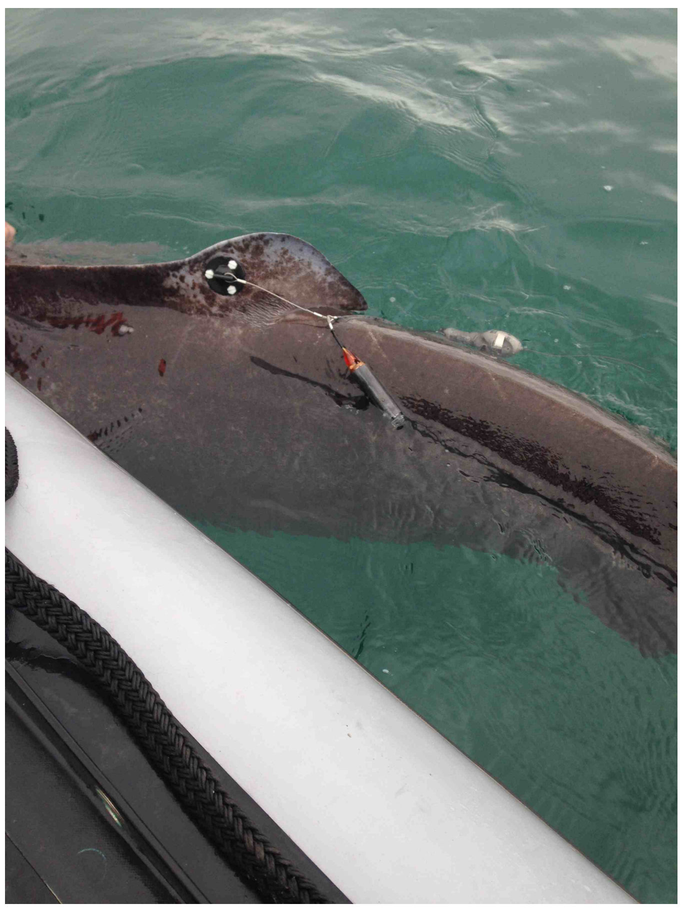

Figure 6: mrPAT and archival pop off satellite tag rig attached via a circular disc plate to the dorsal fin of a Greenland shark in Grise Fjord.

C: Deployment and first results of satellite/acoustic tags deployed on Greenland sharks in Grise Fjord

Fieldwork in Grise Fjord took place from 15th - 28th August 2014. Following the setting of a bottom longline in Grise Fjord after establishing camp (August 16th set at 16:49), two sharks were captured the following day and both individuals were acoustic and satellite tagged (using the combined mrPAT and miniPAT archival tag rig; line pulled at 12:38 August 17th). These sharks were caught in ~21m depth of water in the upper end of the fjord close to where Inuit have previously caught and harvested narwhal. Interestingly, this is the shallowest capture depth for Greenland sharks yet as part of our ongoing research.

The sharks were in excellent condition and were released following work up procedures (Fig. 6). Data for the sharks are included in Table 1.

Table 1: Details of two Greenland sharks caught and tagged in Grise Fjord.

Shark	Date	Haul longline	Start work up	Total length (cm)	Precaudal length (cm)	Sex	Clasper In/Out (mm)	Acoustic ID/SN
1	17th Aug	12:38	12:45	284	231	M	260/60	24541/ 1194518
2	17th Aug	12:38	13:30	270	232	M	200/55	24539/ 1194516

On hauling the lines, sharks were worked up next to the zodiac. Two length measurements, precaudal length (PCL), and total length (TL) were recorded following standard definitions. The animals were sexed based on the presence/absence of claspers; for males, maturity was assessed by level of calcification of the claspers and inner/outer clasper measurements were taken. Minor invasive surgery was then undertaken to implant a VEMCO V16-6H acoustic tag in the peritoneal cavity of the shark, with the incision closed by three interrupted sutures. The circular attachment plate was attached to the shark by drilling three holes through the dorsal fin and bolting the attachment to the fin. As detailed above, the satellite tags were crimped to a stainless steel tether rig, the end of which was crimped to the circular base plate.

For shark 1, the mrPAT was programmed to release from the shark on the 10th September 2014 and the pop off archival tag to collect data for 45 days and release on the 27th September. Both of these tags successfully reported data to satellites. The mrPAT worked as planned and provided the required location data. The pop off archival tag downloaded a total of 4,747 messages during 846 satellite passes. The last transmission location of the mrPAT tag was off northwest Greenland, a straight line distance of ~245 miles from the tagging location (Fig. 7). The last transmission of the pop off archival tag was close to the mrPAT tag (~45 miles; Fig. 7), suggesting the animal had remained in that region for a period of time.

Figure 7: Pop off transmission location of mrPAT (red star) on the 10th September 2014 and miniPAT (green circle) on the 27th September 2014 attached to shark one. Green square marks tagging location.

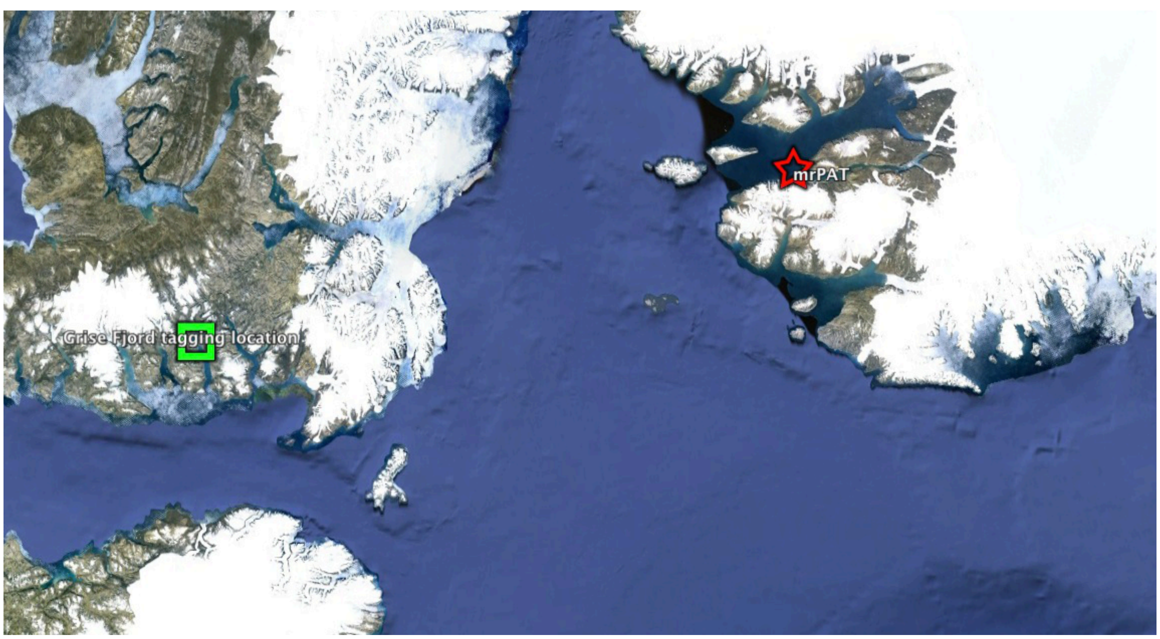

Figure 8: Pop off transmission location of mrPAT (red star) attached to shark two on the 27th September 2014. Green square marks tagging location.

The depth-temperature time series data for shark 1 showed that it stayed in shallow waters for 3 days following tagging (typically <20m), moved deeper but returned to shallower waters on the 21st August (~50m) and to the surface on the 16th September (0m; Figs. 9,10). Throughout the monitoring period, the shark spent most of its time between 200 and 400m depth (Fig. 11) and at ~2°C (Fig. 11), although a biomodal temperature distribution was observed (2 and 0°C).

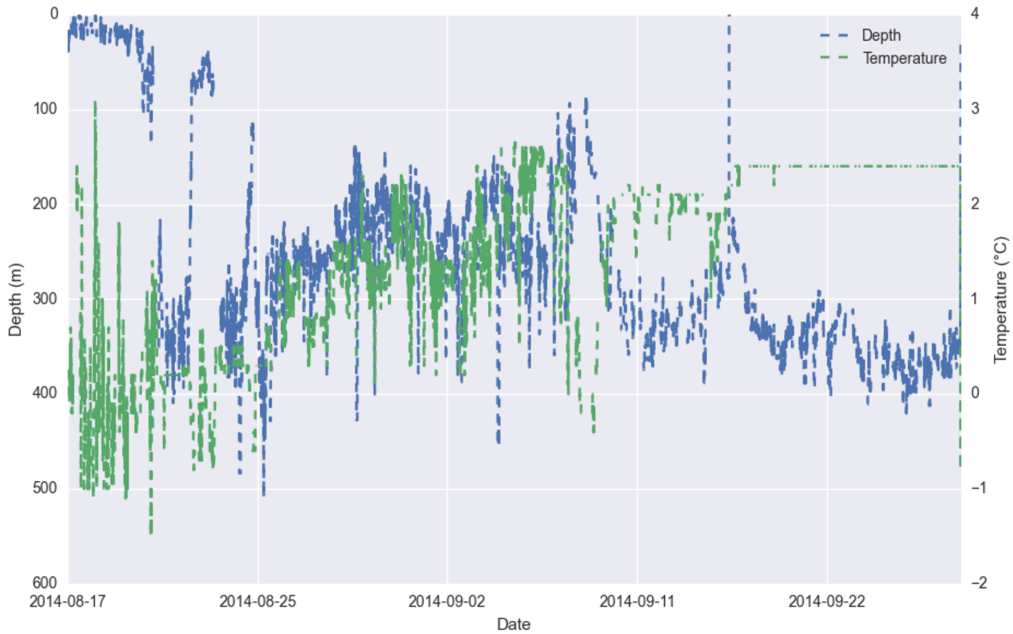

Figure 9: High-resolution depth-temperature time series data for a 284 cm TL Greenland shark tagged in Grise Fjord for 45 days [shark 1].

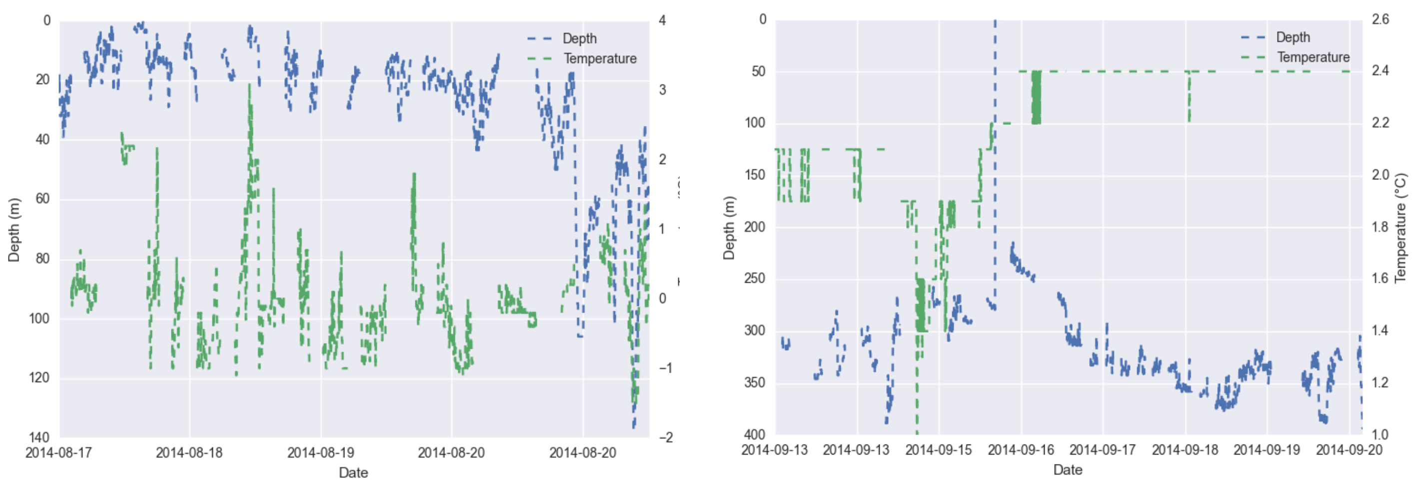

Figure 10: Fine-scale data on shallow water swimming behavior of Greenland shark at the beginning of monitoring and on the 16th September [shark 1].

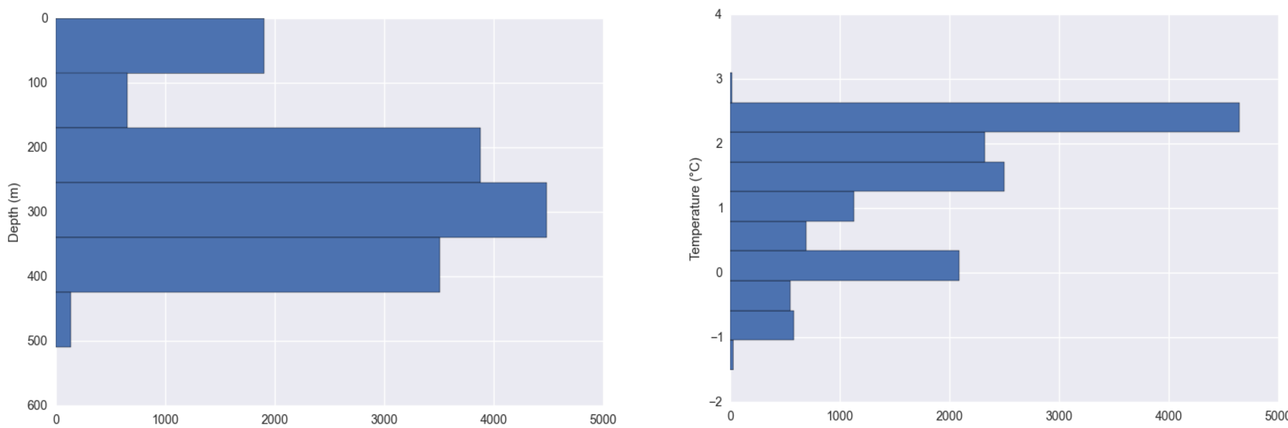

Figure 11: Binned depth (every 100m) and temperature (0.5°C) data for 284 cm TL Greenland shark (Somniosus micorcephalus) [shark 1].

For shark 2, the mrPAT was programmed to release from the shark on the 27th September 2014 and the pop off archival tag to collect data for 365 days and release in August 2015. As above, the second mrPAT successfully transmitted to satellites providing a location close to that of shark 1 within an embayment of northwest Greenland (~90 miles straight line distance; Fig. 8). We await data transmission from the archival pop off satellite tag in August of this year (2015).

Longlines were set every subsequent day of fieldwork and the final line retrieved as we left Grise Fjord following breaking camp. We caught one additional shark on August 24th and attached a satellite tag rig as above. We observed the shark for approximately 30 minutes following the tagging procedure where it remained swimming at the surface. The shark appeared in very good condition and was swimming strongly, but the team leader (Hussey) had concerns over the surface swimming behavior of the animal. We therefore recaptured the animal, by looping a rope around the caudal fin and removed the satellite tag. The shark swam off strongly and then dived. This shark was also a male and measured 246cm total length. No additional sharks were caught. In addition, no other organisms or bycatch were captured on the bottom longlines.

Unfortunately, throughout the fieldwork, no narwhal were seen or caught which limits comparative tracking data. It is also interesting to note that there was obvious animal activity (birds etc) during the first two days of fieldwork when the sharks were caught but then the system seemed to go very quiet. It is possible that Greenland sharks did not enter the system in their normal numbers (as noted by local residents of Grise Fjord) if they are following the narwhal as we predict. Speaking to local Inuit in Grise Fjord, they recommend that if we do not capture sharks inside the fjord next year, that it would be easy to capture them at the entrance to Grise Fjord, near to the community.

UPDATE ON RESOLUTE GREENLAND SHARK SATELLITE TAGGING (2013-2014)

Five Greenland sharks were equipped with acoustic and pop up archival satellite tags in Resolute Bay in 2013. All satellite tags were programmed for >365 day deployments with expected pop off in August 2014.

All five tags popped off sharks in 2014 and successfully transmitted data to satellites (Fig. 12), although one tag malfunctioned and the data were not useable. The success of these long-term deployments was a result of using the newly designed circular attachment plate. Depth-temperature time-series data for the four tags are shown in Figs. 13-16.

Figure 12: Pop off transmission locations for 4 pop up archival satellite tags (miniPATs) deployed on Greenland sharks for >365 day deployments in Resolute Bay 2014.

Of these four sharks, three provided high-resolution depth-temperature time series data for the entire deployments; the fourth tag provided data for the first month and then showed strange behavior. It is possible this last Greenland shark was caught on fishing gear and was potentially cannibalized by another shark (when the tag moves back up to mid water depth) and then that shark regurgitated the tag. The tag would have sunk to the bottom until the pop off date, as it would have still been connected to the leader and disc attachment. Shark 5 moved the largest distance of ~505 miles to northwest Greenland.

Sharks 3, 4 and 5, showed similar depth profiles, occupying an average depth of ~300m over the monitoring period, but with sporadic deep dives. The deepest dive recorded was to 1300m. Given bathymetry maps of the region, we would suggest that these depth ranges are constrained by bathymetry supporting our hypotheses that these animals undertake oscillating dives tied to the benthic environment. This contrasts many pelagic sharks species such as the blue shark (*Prionace glauca*) where diving profiles are tied to the surface. This bodes well for our horizontal location modeling work (see below). In addition, these three sharks experienced a marked seasonal shift in water temperatures. Between January and late June, the temperature encountered by all sharks increased to

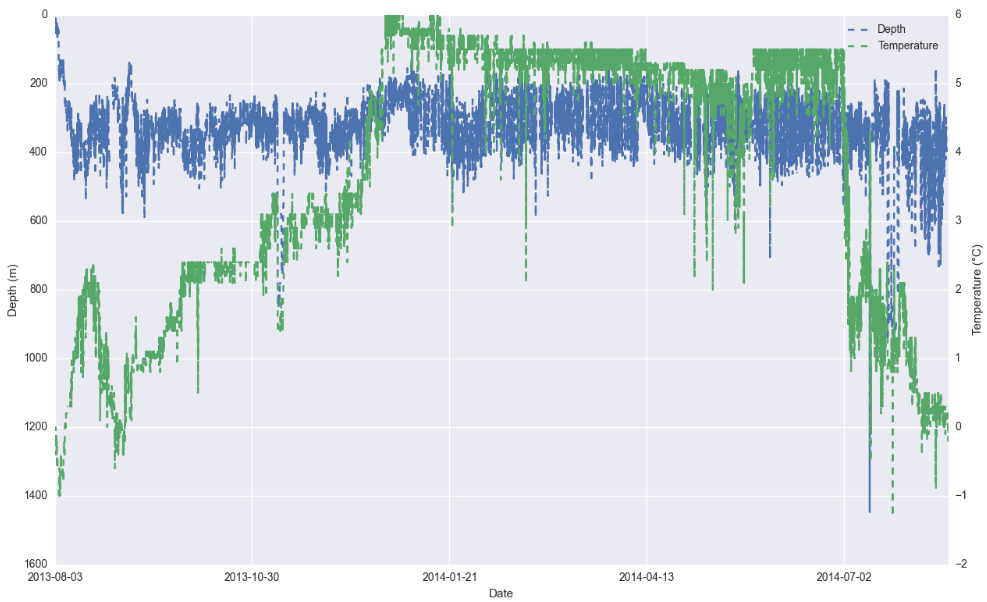

Figure 13: High-resolution depth-temperature time series data for a 320 cm TL male Greenland shark [shark 3].

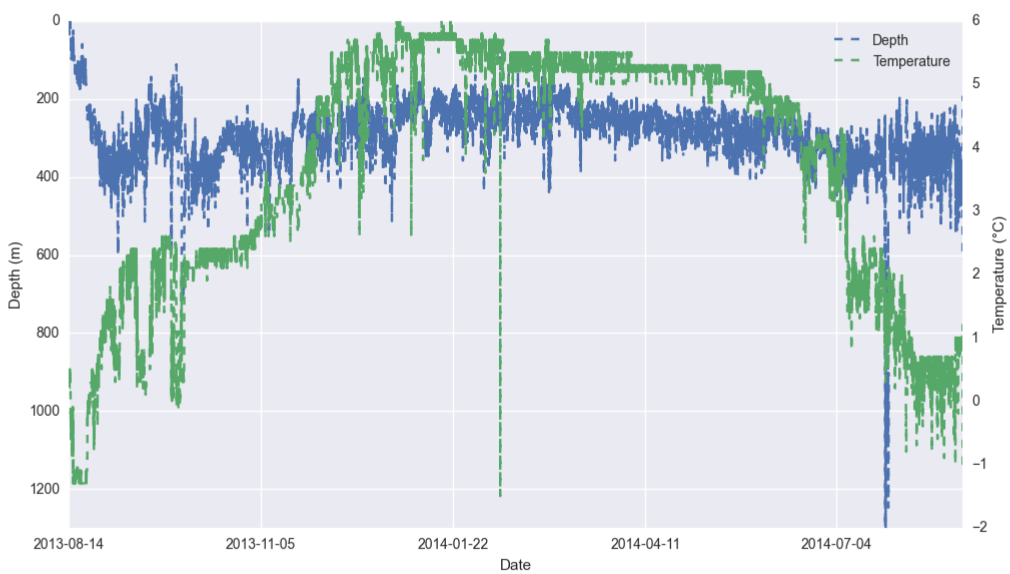

Figure 14: High-resolution depth-temperature time series data for a 306 cm TL male Greenland shark [shark 4].

and remained constant at around 5°C. This may indicate that water temperature can be used as an additional parameter to constrain horizontal location modeling work. All sharks also exhibited yo-yo diving patterns that were typically constrained within certain depth limits (~100m) and replicate dive patterns of sharks monitored at Scott Inlet and Cumberland Sound.

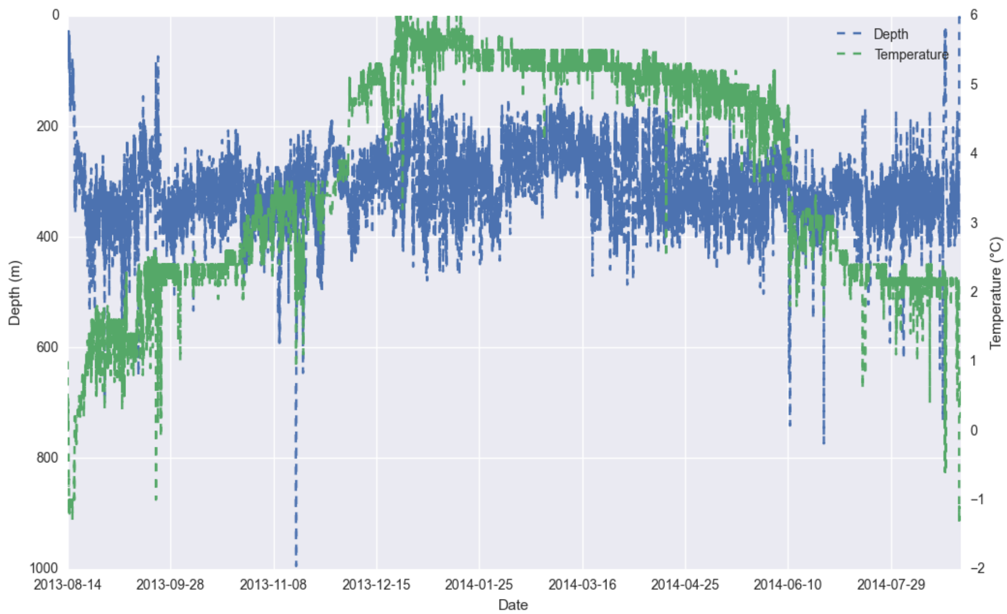

Figure 15: High-resolution depth-temperature time series data for a 280 cm TL male Greenland shark [shark 5].

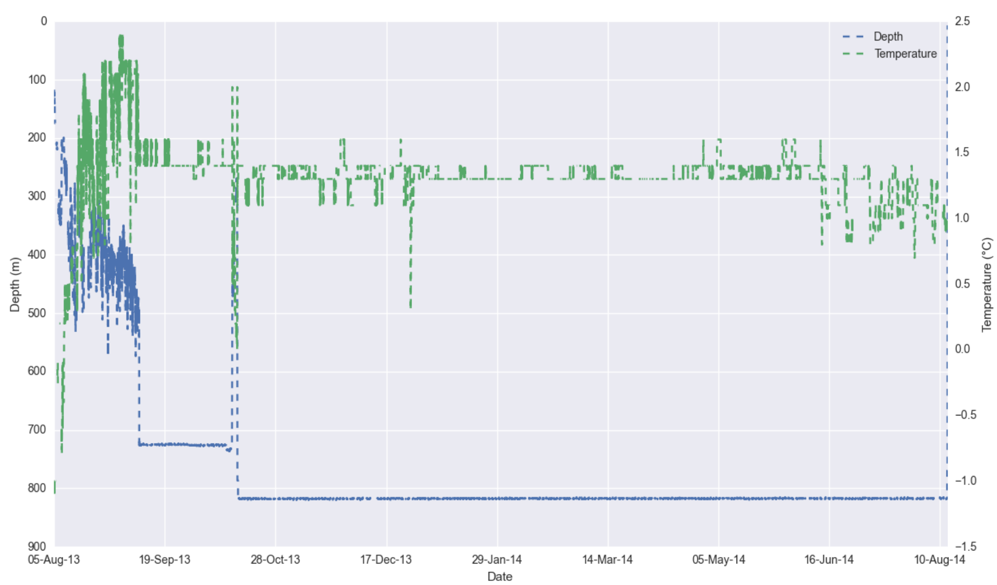

Figure 16: High-resolution depth-temperature time series data for a 268 cm TL female Greenland shark [shark 6].

In general, these high Arctic sharks inhabited shallower waters limited by the bathymetry of the environment, compared to sharks tagged at southern locations. Binned depth and temperature data for all Resolute (n=4) and Grise Fjord (n=1) pop up archival tags clearly show that all sharks typically occupy an average depth of ~300m with a bimodal temperature distribution of 2°C and 5°C.

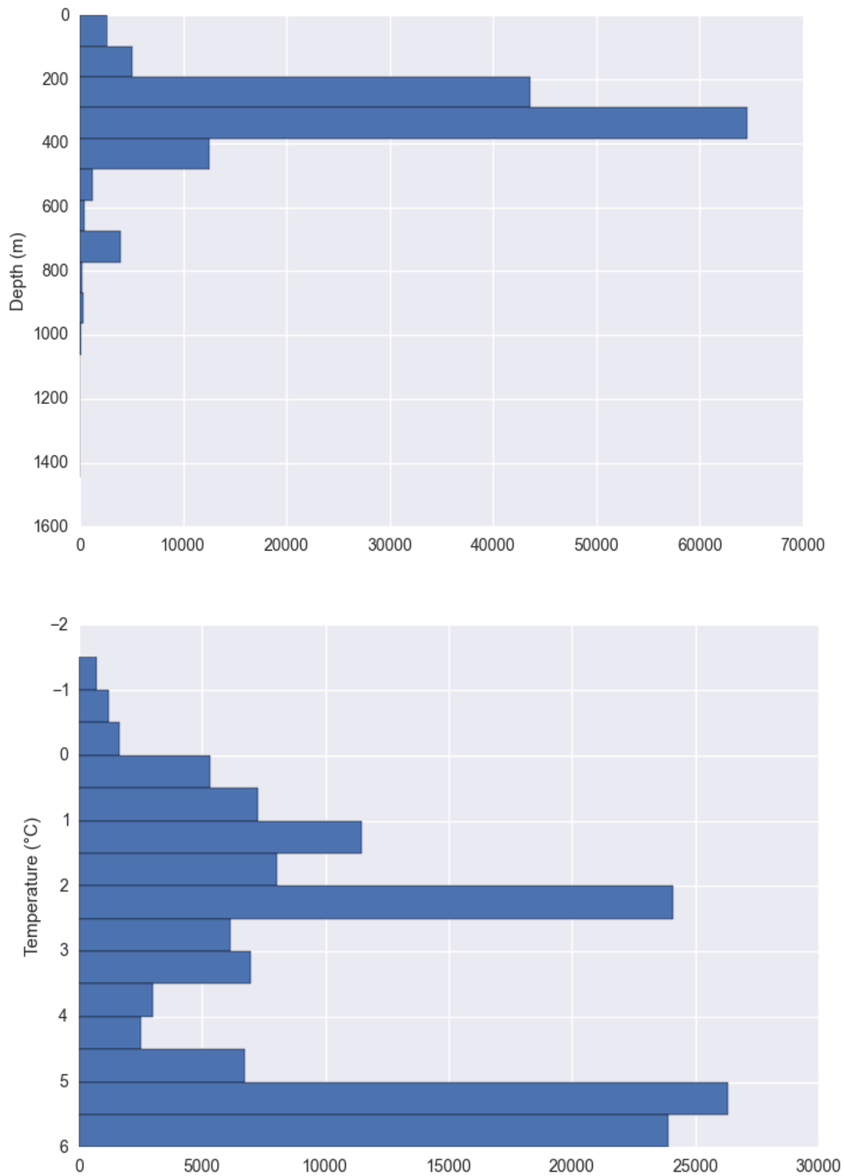

Figure 17: Binned depth (every 100m) and temperature (0.5°C) data for all high Arctic Greenland sharks [n=5].

ONGOING WORK

These data analysis represent the beginning stages of more detailed long-term work. I summarize this below:

(1) Currently an undergraduate student at Dalhousie University is working on these data using the R-package "divemove". These analyses must be adapted for this species, similar to work undertaken on whale sharks (*Rhincodon typus*; Thums et al. 2012, Evidence for behavioural thermoregulation by the world's largest fish. The Royal Society Interface), but will allow fine scale investigation of vertical dive behaviors in this little known Arctic species. Specifically, these analyses will determine how many discrete vertical dive behaviors are exhibited by Greenland sharks and provide detailed parameters for each behavioral type (duration, occurrence rate etc. throughout the monitoring period). For example, fine scale data indicate periods of time when the sharks undertake oscillating dives, potentially searching for prey, but then sharks will remain at one depth, possibly indicative of feeding (Fig. 18). This first investigation will allow generation of new testable hypotheses using for example, accelerometers and long-term video work (e.g. critter cam). This aspect of research will from the basis of Cailin's undergraduate thesis. Cailin is an exceptional student and has the support of the Ocean Tracking Network and statistical management team to address these questions. The work will be completed and we aim to publish a scientific peer reviewed publication in early 2016.

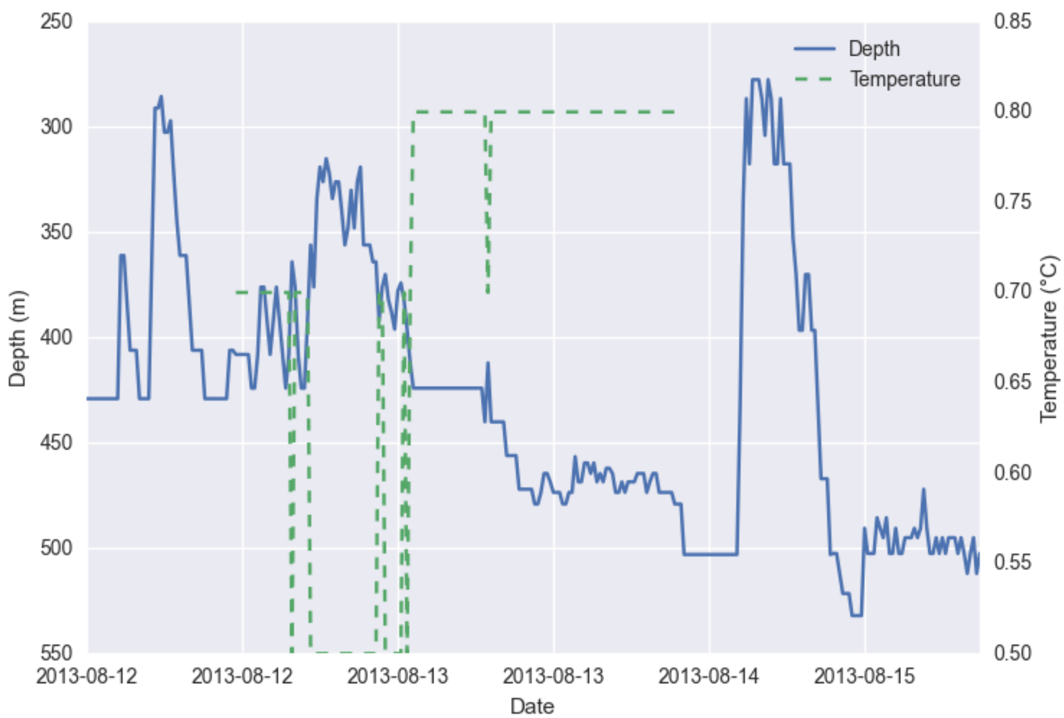

Figure 18: Fine-scale vertical dive data of a Greenland shark showing two distinct behaviors; (i) oscillating dives and (ii) periods of time restricted to one depth.

(2) The senior investigator Hussey is attending a workshop on the "Template Model Builder" for modeling telemetry data in Halifax in mid June. Data from these Greenland sharks have been submitted to the workshop and discussions held to develop vertical state-space models. These models, similar to current horizontal applications, would break

the data into discrete continuous components based on a Bayesian modeling approach complementing but advancing the R divemove package;

(3) Project collaborator, M.A. MacNeil a Senior Research Scientist (statistics and modeling) working for the Australian Institute of Marine Sciences (AIMS), used these data in a recent meeting in Melbourne on, "Hierarchical Bayesian statistics to tackle complex questions in ecology". This ongoing work is building on the above two aspects of research but also examining how the mrPAT tags can be used tackle the issue of bathymetric modeling to derive horizontal location estimates for deep water species.

THE FUTURE

Following the successful testing of the mrPAT tags, the project can now push forward in terms of deriving more accurate location data over time per individual animal tied with the pop up archival satellite tag depth/temperature time series data. We have the mrPAT tags in hand plus three miniPAT tags not deployed in Grise Fjord in 2014. In addition, we anticipate that WWF will provide the additional funding originally requested for year two of this project. Wildlife computers are also donating a further three miniPAT satellite tags. These latter tags are a new and modified design and we will be testing them during this field season. At present, discussions are being held with the engineers at Wildlife computers at the University workshop to develop a new device that can be attached to the dorsal fin of the sharks that can hold multiple mrPAT tags per individual animal.

Greenland shark fieldwork will continue again in Grise Fjord through the support of the narwhal tagging program (DFO). A three week field season has been planned in August and discussions held with community members to maximize chances of catching and tagging both narwhal and Greenland sharks.

SUMMARY

Grise Fjord (and Resolute Bay) represents the highest location in the Canadian Arctic where Greenland sharks have been caught and tagged. This project, in conjunction with several members of the local community of Grise Fjord, successfully tagged two individuals of which one has already provided comprehensive time series data (one will provide data in August 2015). We also tested new mrPAT tags and associated software; new satellite tracking technology that is currently under development. These tags were very effective and now provide the platform to obtain the required location data to improve lat/long modeling using bathymetry data coupled with pop up archival satellite tag time series data from these deep water dwelling organisms. Comprehensive data analysis is ongoing coupled with further collaborative fieldwork to deploy more tags on sharks in conjunction with narwhal in Grise Fjord. Moreover, this focused high Arctic works complements Greenland shark work also underway in Scott Inlet (Community of Clyde River) and Cumberland Sound (Community of Pangnirtung)