Tracking the movements of rig sharks

by Warrick Lyon

Prepared for the New Zealand Marine Research Foundation

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Contents

Executive Summary

Rig are small endemic sharks, that migrate to sheltered harbours, estuaries, and bays like Porirua Harbour (25 km north of Wellington) to spawn and mate during the spring and summer. I wanted to know what the rig were doing in Porirua Harbour, but the technology to accurately track small benthic sharks did not exist. To find an answer Peter De Joux and I built a tracking system that would allow us to track rig while they were in their shallow water spawning grounds (Porirua Harbour). This tracking system includes a surface-floating tag tethered to a benthic swimming rig and towed around by it. The tag receives GPS coordinates and sends that positional data through an array of routers to a co-ordinating computer on land. With positional data available in real-time the co-ordinating computer creates maps for Google Earth and an interactive map at sharktrack.org.nz The website and Google Earth maps can then be used as tools to raise awareness with local interest groups, and school pupils from primary and secondary schools.

After this tracking system was built and deployed 25 mature rig were tracked to identify their movement patterns. A good number of these tracks were unable to be analysed, but of those that could be, an unexpected pattern was found. The rig showed no signs of having different day and night patterns, nor any tidal patterns, and did not spend all their time randomly swimming over muddy sea floor searching and feeding on their main food source, mud crabs. What rig were doing was spending around half of their tracking periods over the mud sediment, and the other half in a primary channel, a steep-sided, fast flowing channel with little if any food resources.

This research has been taken to primary schools, a college, and an Iwi. This research has been published on the internet, presented in oral and poster form at scientific conferences, and the tracking system published in the Marine Technology Society Journal.

Acknowledgments

I would like to acknowledge the support from the trustees of the New Zealand Marine Research Foundation (NZMRF) for seeing potential in this research, thank you. Additional support for conferences came from the University of Auckland, and the National Institute of Water and Atmospheric Research (NIWA).

I would also like to thank Peter De Joux (NIWA) who is the brains behind the tracking system, Lauren Schaer who designed the website, Simon Nitz (Digital Mapping Solutions) who designed the map on the website, Joshua Barclay (VUW), Christy Getzlaff, Mike Seawright, Jeff MacDonald, Kevin O'Donnell and Emer Beatson helped as field assistants, and Malcolm Francis (NIWA) for scientific advice.

Introduction

Until 10 years ago I did not know that Porirua Harbour, my local estuary growing up in Mana, was full of sharks for half the year. After learning this I wanted to learn as much as I could about the rig that use Porirua Harbour. Rig, which are also known as spotted dogfish (*Mustelus lenticulatus*) are from the Family Triakidae (Smoothounds), and are small endemic sharks found throughout New Zealand waters (Francis and Francis 1992). Rig make seasonal inshore migrations where they congregate in sheltered harbours and estuaries like Porirua Harbour to spawn and mate during spring and summer (Graham 1956; Francis and Mace 1980; Francis 1988). Rig give birth from late October to early December (Jones and Hadfield 1985; Francis and Francis 1992), when juveniles are born at 20–30 cm TL after an 11 month non-placental ovoviviparous gestation period (Francis and Mace 1980; Francis and Francis 1992). Following that, is a polyandrous mating where 42 % of litters have more than one father (Boomer et al. 2013). Males reach maturity at 72–87 cm (3.7–5 years) and females between 82 cm (4.7 years) and 102 cm (Francis and Francis 1992). Maximum size and age for rig is 1.5 m for females and 1.2 m for males, longevity probably exceeds 15 years, and may exceed 20 years (Francis and Ó Maolagáin 2000; Francis 2013).

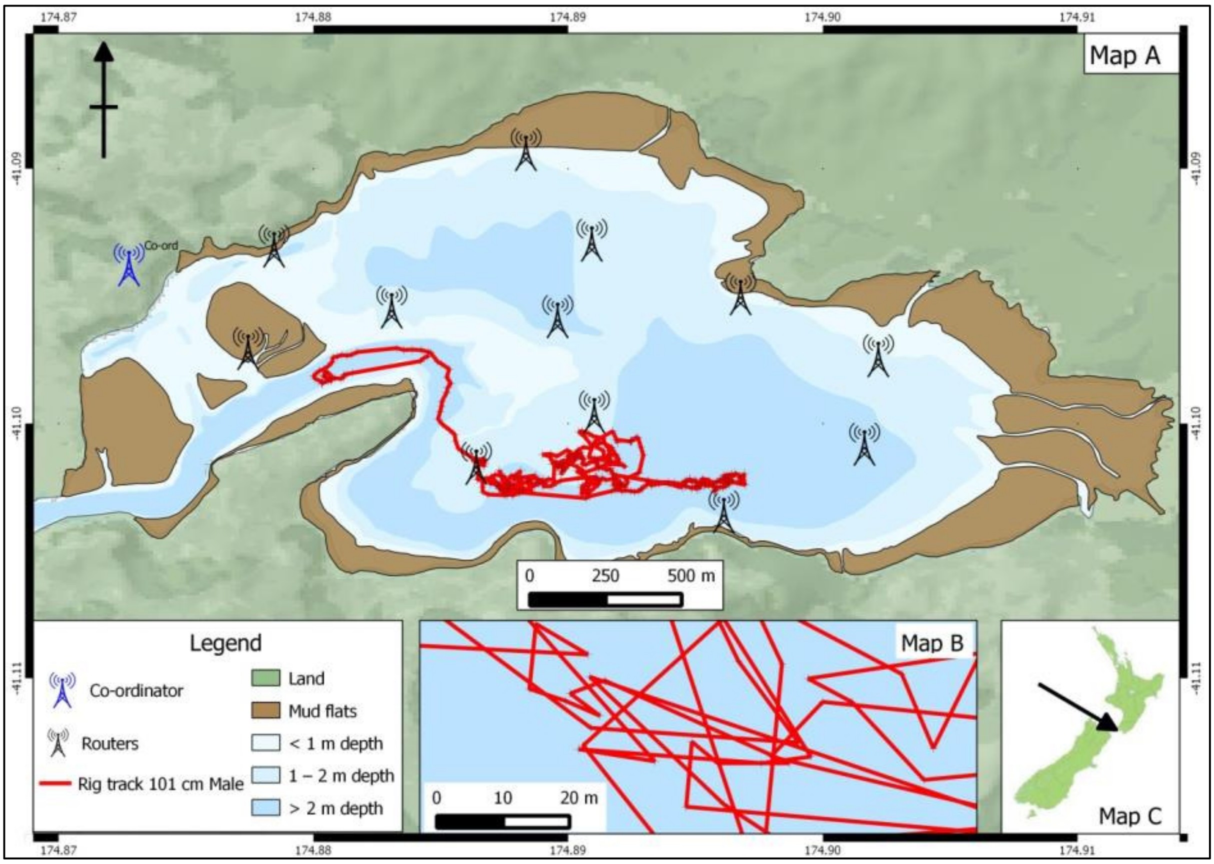

Figure 1: Map A shows Porirua Harbour with on land Co-ordinator, on water routers, and a rig tag track (red), Map B shows an area of track enlarged, Map C shows where Porirua Harbour is located.

A lot is known about rig biology, but I wanted to know i) how many rig use Porirua Harbour? ii) how long do they stay? iii) where in the harbour do they spend their time? These questions led me back to University to undertake a Ph.D. Questions 1 and 2 were easy enough to answer, but how could I learn where the rig spend their time? After looking at the tracking technology available and finding that the only viable way to track the long term movements of rig (acoustic tracking) had very poor positional accuracy ~300 m, I decided I needed to find a different way to find where rig spend their time. I then asked a colleague if we could build our own tracking system that would tell me where the rig were moving within Porirua Harbour with accuracy of around 10–15 m. After discussing a number of options that included, triangulation, and using cell phone technology we decided on a GPS receiver combined with a radio transmitter that were housed in a float that remained on the water surface and was towed around the harbour by a 6 m tether between the float and the shark. When developed, tested, and in use these floating tags can send their GPS coordinates a maximum of 500 m in all directions, if the signal needs to travel further it uses a mesh of routers placed around the harbour that then pass the signal back to a coordinating computer on land (Figure 1), where data can be processed in real time.

Being able to collect rig movement data I now have a better understanding of the ecosystem within Porirua Harbour and have been able to pass this new knowledge on to local schools as part of their science or biology programmes.

Objectives

The objectives for this research were to:

1. Build a shallow water tracking system to track rig in Porirua Harbour.

2. Identify the movement patterns of adult rig during their spawning season and to present this information on a website for educational purposes.

3. Speak to five local schools and to local interest groups with the view to passing on the knowledge derived from this research.

4. Publish this research in a peer reviewed journal which will acknowledge your support.

Method

Rig were caught using a set net (permit from Ministry of Fisheries now MPI) that was checked every 15 – 30 minutes for any entangled rig. Once caught, the rig were untangled, total length was recorded, as was sex, and the reproductive maturity of males. If the rig was still lively after this a 5 mm diameter hole was placed in the shark's first dorsal fin and a grommet (or eyelet) set in the hole. The grommet gave the hole added strength for the 6 m long nylon tether that ran between the sharks fin hole and the surface floating Lyon-DeJoux tag. The Lyon-DeJoux tag was used to track the rig while they were in their shallow water spawning site, and has three parts, two on the water (the surface floating tags and the routers), and one on land (the coordinator).

On the Water

The 'Lyon-DeJoux Tags' were built from off-the-shelf electronics, and have five main parts (Figure 2). Put simply, the GPS receiver is woken up by the microprocessor, and the positional data received from GPS satellites, the positional data is then sent via the transmitter and its aerial-extension on the tag housing, and rechargeable batteries allow the tags to be reused when needed.

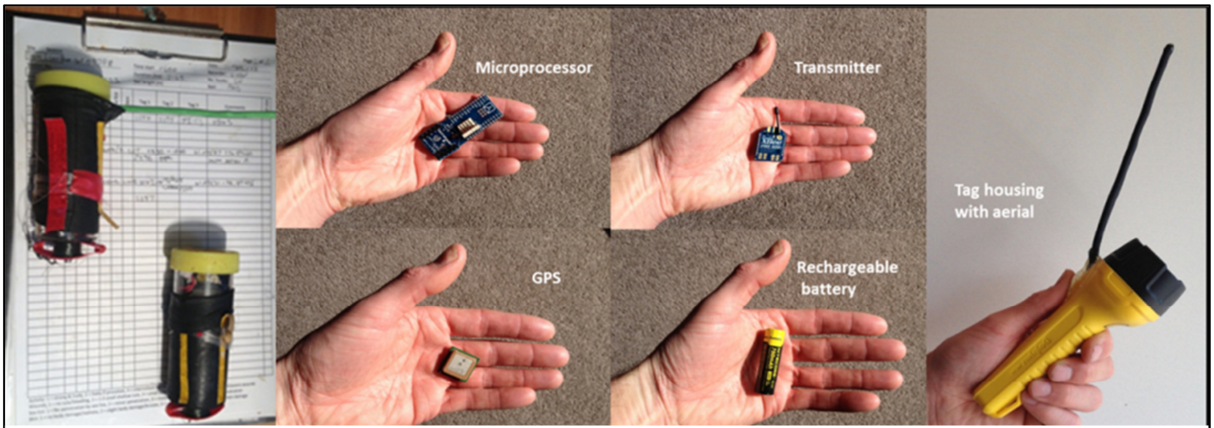

Figure 2: In the left panel a Mark-1 and Mark-2 (with green aerial) tags, the central images are of the tag electronics, with the waterproof housing for the Mark-3 tag on the right.

Ten Mark-3 tags have been built and now only 1 remains in useable condition. Over the time of this project five tags were attached to rig and then never seen again for unknown reasons. One tag housing leaked and two tags died from corrosion, and in three tags the GPS receivers stopped working. One Mark-1 tag was lost and returned by a member of the public, and three run-away tags were collected after coming free from their sharks.

The Routers are the second part of the on-water part of this tracking system. The routers have gone through a significant redesign from the initial floats floating on the sea surface (Figure 3) to the tall design (Figure 4) where the transmitting aerial is at least 1 m above the high tide level. The higher router position allows much better transmission of radio waves (which cannot pass through water) between each of the routers in the mesh-network, as well as better reception of transmissions from the tags. Ten of these routers were built and only 7 remain. After losing 1 router in a storm, 1 because of bad welding, and 1 to theft, the routers were anchored to the seafloor by two x 3 – 5 metre long steel warratahs (y-posts).

Figure 3: Round router with electronics positioned at or below water level.

Figure 4: Tall routers with the electronics positioned high above the water.

On Land Processing

On land is a co-ordinating computer that runs the shark tracking system. All tag positional data is sent from the tags through the routers to this computer. The computer saves all the positional data in the Cloud, and also onto the hard-drive. The coordinating computer also makes Keyhole Markup Language (.kml) files from the positional data and saves these files to the Cloud. These .kml files are opened using the Google Earth App on a smartphone (Figure 5) or Google Earth on any computer to show the current position of any tagged shark.

Figure 5: Google Earth files showing shark positions were saved to the Cloud and accessed by smartphone Apps to locate tagged sharks

The co-ordinating computer also sends emails. It monitors the tag positions and when a tagged shark begins to leave the Harbour, it sends an email saying just that. Additional emails are sent when the tag battery runs low and needs changing. If either email is received, a smartphone can be used on the water to find the tagged shark, then a tag with a low battery can be removed and replaced for one with fresh batteries, or the tag and tether removed if the shark is leaving the harbour.

The accuracy of the GPS positions is unfortunately highly variable with some errors placing the tags several kilometres from the harbour. This variability in the GPS positional accuracy can be removed by using differential GPS. We decided against this and had to find a way to filter the erroneous positions from a rig rack. It was noticed that when the GPS satellites got a position wrong, the satellite also got the altitude wrong. This meant the altitude data could be used (using only GPS positional data if the altitude value was between -30 m and + 30 m) to remove any likely erroneous positions. The importance of this filtering is shown in Figure 6, the yellow track shows the filtered positions where the GPS satellite altitude measure is between -30 and+30 m, removing almost all the 'erroneous' red spikes from the rig track. The yellow track is a more likely course that hopefully matches the true course taken by rig T2362.

Figure 6: A five hour filtered track of a rig is shown in yellow, the outlying points (shown in red) were removed by using 'altitude' as a filter.

Once the positional data from the rig tracks had been collected by the co-ordinating computer they were loaded into a database where the tracks could be analysed. Unfortunately, with only a small number of tracks recorded so far, a strict statistical analysis of the movement data could not be undertaken. However, the tracks could still be analysed using GIS software such as QGIS which was completed. Within QGIS all the filtered rig positions were layered, with additional layers of tide times, day-night and crepuscular periods to see if any patterns emerged. Rig positions were highlighted if occurring within one hour before and after the high or low of the tide, or one hour either side of dawn and dusk to look for movement patterns.

Results, discussion and conclusions

It was hoped that 100 days of rig tracks would be collected but only ~100 hours of rig tracks (Table 1) have so far been collected. There have been many unforeseen development problems that have occurred during the last two years which have mostly arisen from the tag housings and router programming. The target of 100 days of rig tracks still stands and is hoped to be met by the end of the current 2014-15 season.

Table 1: Tagged rig details, including biological measurements (M3 is a mature male), track length, and the season tagged, all are within Porirua Harbour.

Tag number	Length	Sex (stage)	Time (hours)	Season (year)	month
	83	M3	2	2012-13	January
	105	F	3	2012-13	February
	110	F	5 mins	2012-13	February
T2329	95	M3	18	2013-14	February
T2348	93	M3	16	2013-14	March
T2399	101	M3	31	2013-14	March
T2387	94	F	3	2013-14	April
T0100	95	M3	1	2013-14	May
T2364	92	M3	13	2014-15	December
T2362	90	M3	5	2014-15	December
T2360	101	M3	6	2014-15	December
			93 hours		

Data summary

Twenty five rig were tagged with GPS tracking tags, but only 8 shark tracks were good enough to be used in this analysis. This was because one shark died very quickly after tagging and never moved, 2 tags released from the shark within an hour of tagging and the tracks recorded were the tag moving with the tide, and one tag got caught around seafloor debris and the rig moved nowhere but round and round for half a day. Additional tag losses occurred when the tags came loose from the sharks due to tether twisting, tag transmissions ceased (for unknown reasons), or any other unidentified reason. Over 3 seasons ~200 hours of rig tracks have been monitored, with 93 hours of tacks able to be analysed with ~5,500 positions, an average of around 1 position every minute. The first 3 tracks collected (Table 1) weren't included in the analysis because the tracks were made from a boat with a GPS following the tagged rig.

Rig movements

Rig tracks were examined for any tidal or diel patterns, with rig positions during low and high tides, dawn or dusk, and night or day were highlighted (Figure 7). With only 6 tracks including a full tidal cycle, and only 2 tracks incorporating more than 2 tidal cycles, the opportunity for recognising any tidal influenced movement patterns was limited. The same was true with crepuscular, and day or night patterns with too few occurring during tracking periods.

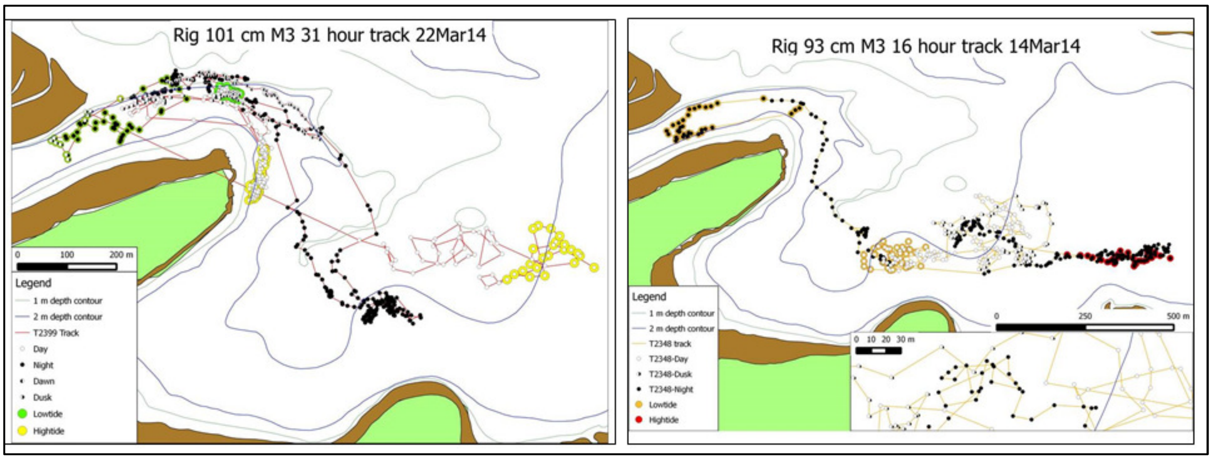

Figure 7: Two rig tracks with positions highlighted during high and low tides, day or night, and crepuscular periods.

No diel patterns nor tidal patterns were recognised from the QGIS analysis. What was recognised was regular movements of all but 2 rig into the fast flowing deep sided channels (Figure 8) during any time of the day, the night, or tidal cycle. These channels were used between 1 and 12 hours, through low, mid and high tides, some sharks went into the channel and immediately left, others stayed most of the day and night. This movement into the channels was never one of the scenarios predicted at the start of this research, it is possible that another biotic or abiotic factor (not tidal or diel) could be influencing these movements.

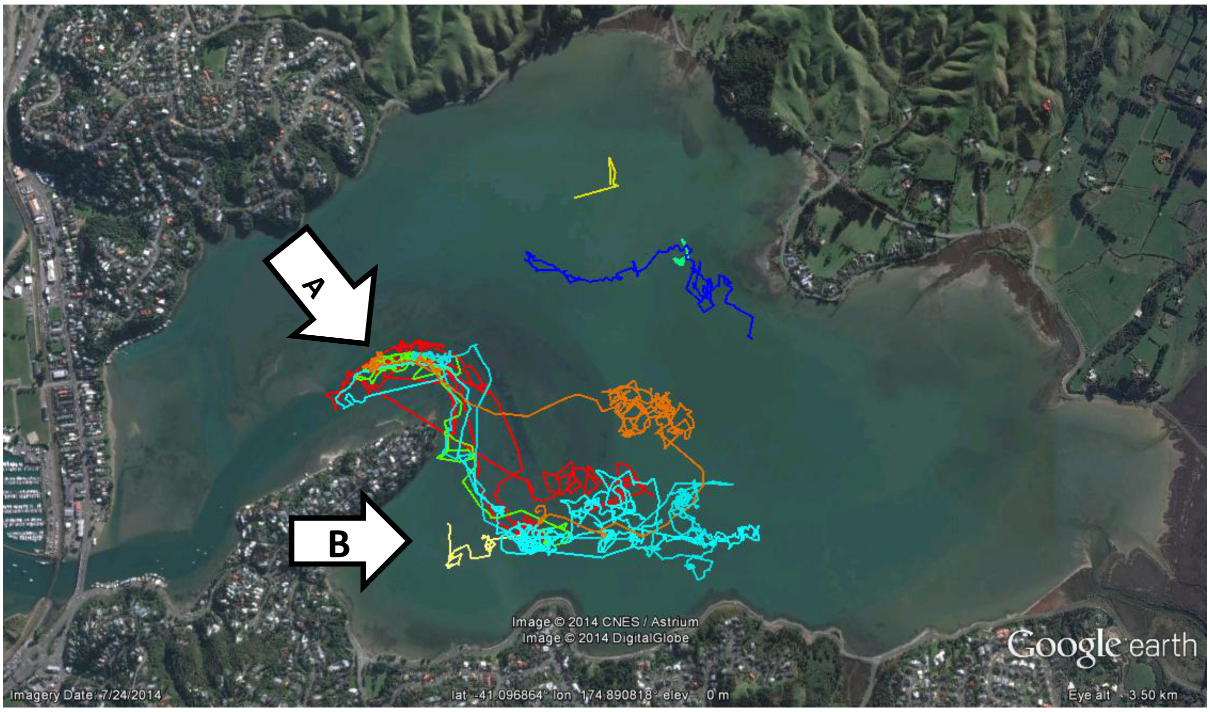

Figure 8: Eleven rig tracks within Porirua Harbour, showing two main areas of use, in a deep fast flowing channel (arrow A) and the southern edge of the harbour (arrow B).

The tracks made by rig may not show any tide or day-night cycles, but they do identify directed movements by most of the rig from one centre of activity to another (Figure 8, 9). Of the 11 rig tracks plotted in Figure 8, eight have directed movements between the two activity centres. The two areas are considerably different, Area 'A' is mostly a deep, fast flowing and steep sided channel with very little food, Area 'B' has low current flow, is shallow, with a mud seafloor with lots of the rigs preferred prey. Two of the rig (with longer tracking periods) made multiple movements between the two centres. It can be concluded from the rig tracks that the directed paths between the two activity centres indicate that the rig know where they are going. The rig are not randomly swimming around the harbour unaware of their surroundings. This behaviour has been observed in some shark species, mostly larger more pelagic species such as tiger, scalloped hammerheads, great white, blue and mako sharks (Klimley 1993; Klimley et al 2002; Heithaus et al 2002), but never by any rig-type sharks (Smoothhound sharks). This is more likely due to small sharks being hard to track accurately (until now) rather than only rig showing this behaviour.

Additional movements have been identified from some rig tracks and have been likened to 'searching' and 'focused' activities (Figure 9, Map C, Map D). 'Searching activities' have been identified as ~50 m diameter loops where the rig move quickly (10 – 15 minute loops), while 'focused' activities are localised to ~30 m diameter areas for longer periods of time (26 – 50 minutes). It cannot be said what has focused the attention of the shark, only that it has been focused. It is possible that the focus has been on food. Further work planned to identify prey densities across the harbour will offer greater insight to these 'focused activities'.

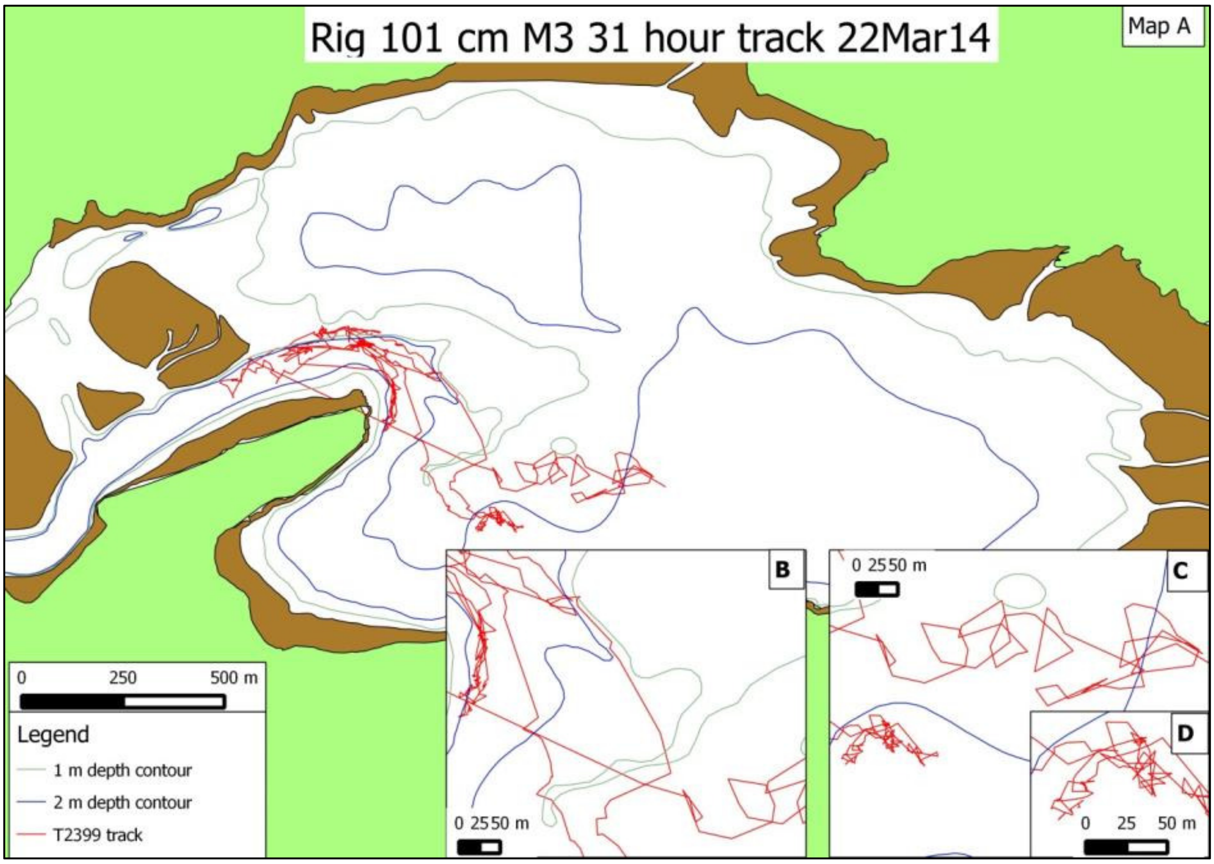

Figure 9: A single 31 hour (8.5 km) rig track in red (Map A), highlighting directional movements (Map B), searching movements (Map C), and focused attention (Map D).

Changing monthly patterns

Monthly variations in rig movement cannot be rigorously analysed, due to a lack of tracks in different months. However, tracks from the tail end of the season (May), are matched by those at the start of the season (December). During both months tagged rig have moved into the main harbour channel. It is likely that the movements shown by our tagged rig will be similar during other months of the season, with only slight seasonal changes likely.

Rig preferences for benthic substance

Rig seem to prefer the hard shell or sand seafloor found in the harbours primary channels, as well as the shallow mud that makes up most of the harbour. Less than 1 % of rig tracking time was spent over sea grass, or sand bars. When this did occur it was as the shark was transiting those areas moving somewhere else. It was anticipated that rig would spend much of their time swimming over muddy sediment feeding on their preferred prey of mud crabs. This is partially true (Figure 8 arrow B) with rig spending about half of the tagging periods over muddy sediment, likely searching for food. The remainder of the tagging periods are spent in the main channel where the seafloor has only polychaetes (which are not highly placed in a rig diet (Getzlaff (2012)) and no mud crabs.

It is fascinating that the rig are behaving in a way that is completely unexpected, spending time in the channels. It will be an enjoyable challenge trying to work out why this is.

Outputs

Public presentations (Schools, interest groups, and Marae visited)

November 2013, Plimmerton Primary School
March 2014, August 2014, Aotea College
April 2014, Ngati Toa
November 2014, Pauatahanui Primary School
Booked 2015, Guardians of Pauatahanui Inlet

Publications (electronic and print)

The Marine Technology Society Journal (attached)
NZ Science Teacher (accessible via link if you have a log-in)
http://www.nzscienceteacher.co.nz/curriculum-literacy/the-living-world/keeping-track-of-local-sharks/#.UvwIY_LXrxV
Rig shark tracking website http://sharktrack.org.nz/ (screen print in appendix)

Conference Presentations

Oral
August 2014, NZ Marine Sciences Society, Nelson, New Zealand (Slide 1 and Abstract in Appendix)
Poster
July 2012, Oceanic Chondrichthyan Society, Adelaide, Australia (Appendix)
September 2014, Bio-Logging Symposium, Strasbourg, France (Appendix)

Project material development

There has been considerable improvement of the original tracking system from 2012 with all 3 parts (tags, routers, co-ordinator) receiving improvements. The tags now have faster responding GPS receivers, longer lasting rechargeable batteries, and better water-proof housings with higher placed antennas. The Routers have evolved from surface floats to tall units (to transmit over the waves) with higher gain antennas. The Co-ordinator has an even higher gain antenna, running Python code that now produces positions in decimal degrees, and saves data to a database running in the Cloud. This allows real-time plotting of shark tracks on a purpose built website by Digital Mapping Solutions.

Extension and Adoption

This project will continue to grow for a further 4 years as part of my Ph.D. research through the University of Auckland. Additional schools and interest groups will be visited with arrangements developed through the Greater Wellington Regional Council and the Healthy Harbours Porirua – Outreach Programme. Additional scientific publications will also be completed.

A researcher from England (Dr Matthew Witt) has shown interest in using this tracking technology to track basking sharks in southern England.

This research will continue, I am hoping that as time goes on the track periods will get longer and longer, as small failings are identified and rectified, tag development will never cease.

Financial summary

W LYON	Original = **$15000**	Field Assistant = **$6000**
Paid		
24.10.12	2133.57	
12.11.12		6000
04.02.13	3635.88	
11.11.13	3794.84	
Website	2000	
Final Report	3435.71 (from $4000)	
Totals received	$9,564.29	$6,000

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Appendix

Appendix 1 – Outputs

The Marine Technology Society Journal – A paper on the tracking technology itself. With NZMRF acknowledgement on the last page. See attached paper.

TECHNICAL NOTE

A Tracking System for Sharks in Shallow Water

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ABSTRACT

A shallow-water shark tracking system was developed to track a floating tag towed behind a medium-sized shark as it swims around a shallow water estuary. The towed float contains a GPS receiver, an Arduino Fio microcontroller, and an XBee Pro (low-powered digital radio transceiver module) for radio frequency (RF) transmissions. The receiving system uses XBee Pros as RF routers, positioned through the estuary, to act as a self-healing mesh network, passing the tag signals back to a coordinating XBee Pro attached to the serial port of a land-based PC. A Python script filters good GPS positions from bad and builds Google Earth Keyhole Markup Language (KML) files. The Google Earth files, loaded from the cloud, allow easy access for biologists with smart phones to access real-time shark positional data. The computer sends emails when tag positional data show a shark leaving the estuary so the tags can be retrieved and also when router or tag battery voltage gets too low and needs replacing.

Keywords: mesh network, GPS, timestamping, Python, KML files

Introduction

Many shark species inhabit shallow coastal waters worldwide. Often, such habitats act as nursery areas for juvenile sharks. In order to determine patterns of habitat use in a small New Zealand shark, we needed to track them in shallow water, in real time, with fine-scale accuracy.

In a 3-km-long estuary with extensive intertidal sandbars and mudflats exposed at low tide, narrow fast-flowing channels, and patchy benthic habitats, positional accuracy must be greater than that offered by acoustic receivers of 18%–30% of pings received at 300 m (Francis, 2013). Getting a more accurate picture of behavior and habitat use could only be achieved by using a more accurate tracking methodology.

With a lack of tags suitable for tracking medium-sized sharks, we designed and built a multiple-shark tracking system using off-the-shelf electronic components to transmit GPS positional data in real time, together with unique identifiers, from a small float towed behind the shark.

After describing the preferred habitat of rig sharks and discussing the conventional shark tracking options, we define and explain the technical and scientific aspects of this tracking system in two parts: what happens at sea and what happens on land.

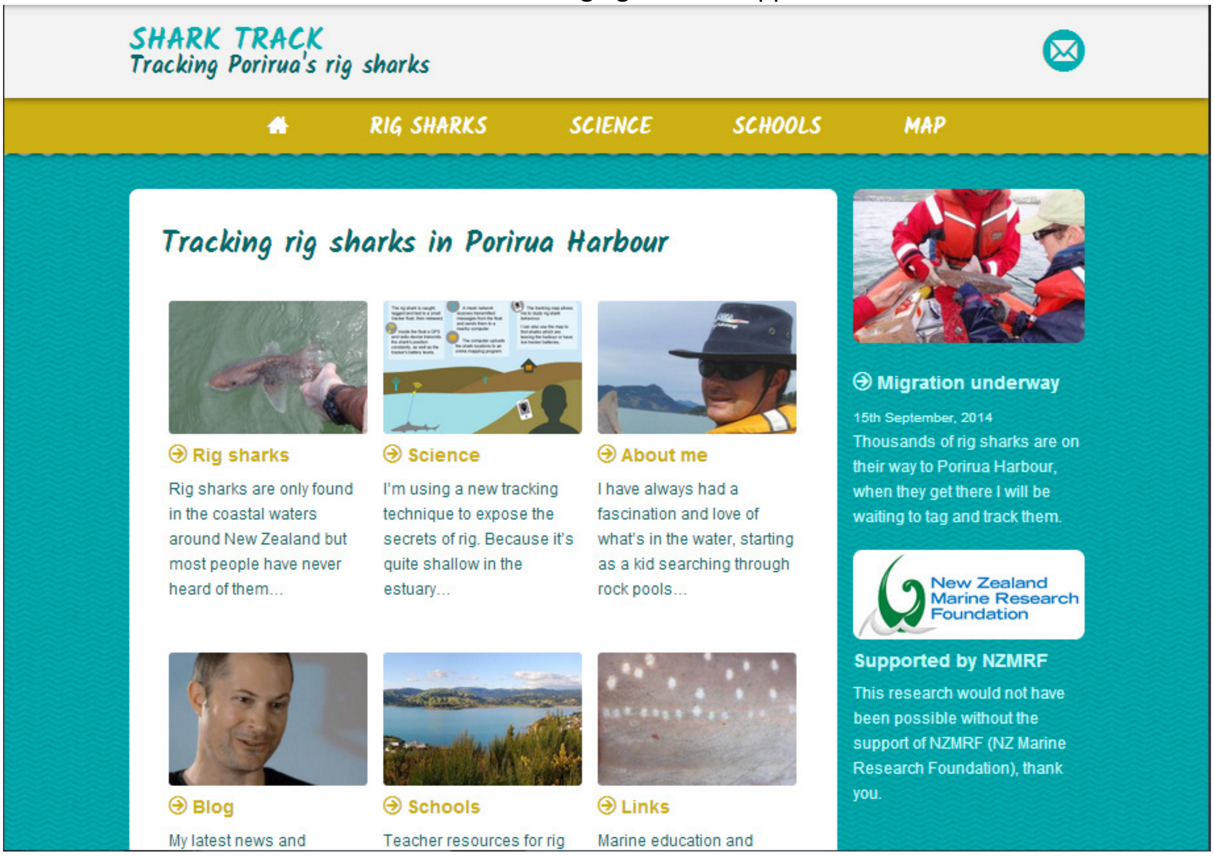
Rig Sharks (*Mustelus lenticulatus*)

This research would have been much easier if rig sharks came repeatedly to the surface to breathe air, like whales, dolphins, or penguins, or to swim near the surface like mako or great white sharks. Rig sharks are part of a global family of small- to medium-sized houndsharks (Triakidae). This family contains over 40 species, some of which use shallow protected waters during spring and summer (Compagno et al., 2005). The rig sharks being studied vary in size from 60 to 110 cm and spend all their time on the sea floor, much of it feeding on their preferred prey, the mud crab (*Hemiplax hirtipes*) (Getzlaff, 2012). Rig sharks prefer turbid estuarine waters (Francis et al., 2012)—not clear oceanic waters, but muddy waters where visibility ranges between 10 and 50 cm (pers. obs.)—making it virtually impossible to see the sharks even in shallow water. Like other members of its family (e.g., the gray smooth-hound (*Mustelus californicus*), brown smooth-hound (*M. henlei*), and the Australian gummy shark (*M. antarcticus*)), rig sharks spend spring and summer in shallow coastal estuaries, harbors, and bays (Barnett et al., 2010; Campos et al., 2009; Espinoza et al., 2011a; Francis, 2013; Francis et al., 2012).

Tags on the Market

Methodologies for tracking sharks range from visual tracking using a polystyrene float tethered to the shark to complex electronic tags that measure and record numerous environmental parameters (Medved & Marshall, 1983; Sims, 2010). In

Screen shot from shark track website acknowledging NZMRF support.

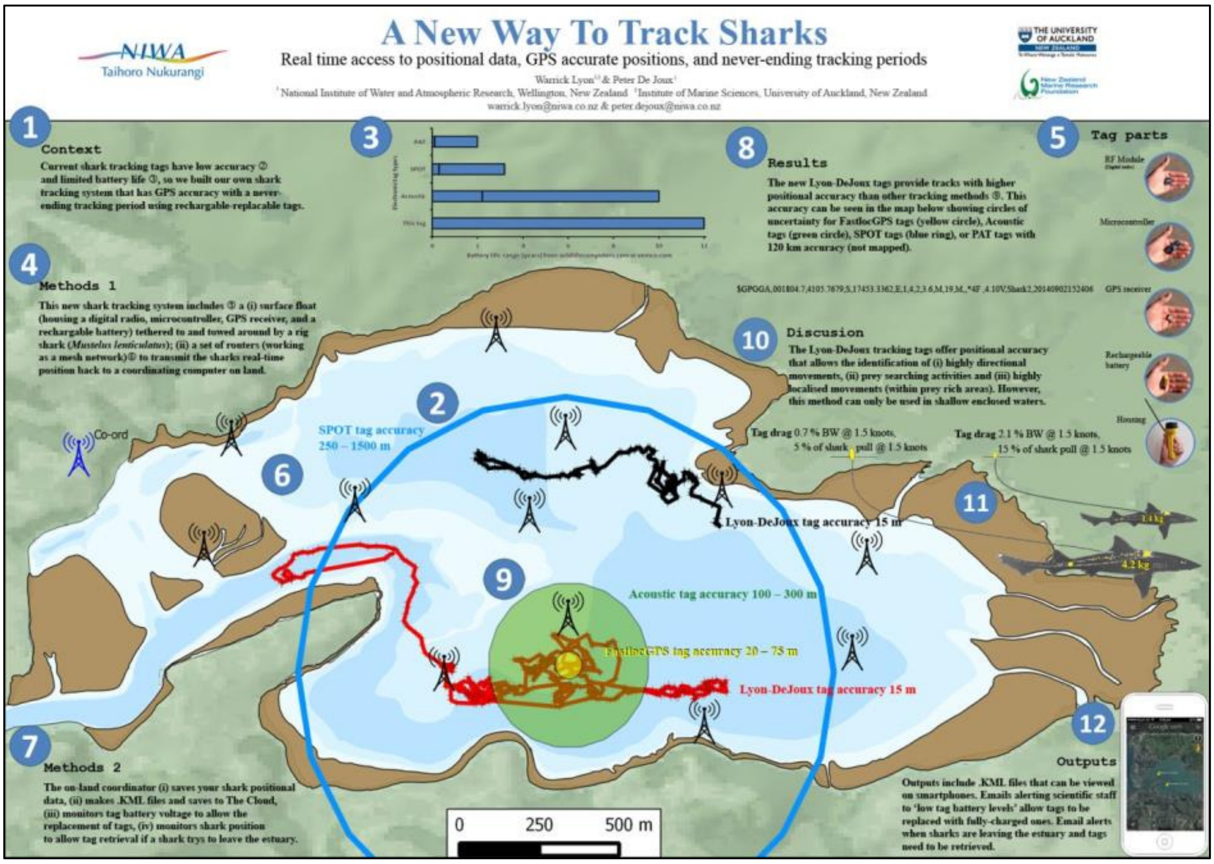


NZ Marine Sciences Society conference August 2014, oral presentation, Slide 1

NZ Marine Sciences Society conference August 2014, oral presentation, Abstract

The fine-scale movements of rig (*Mustelus lenticulatus*) have been recorded from a spawning site in a shallow water estuary using an innovative tracking system. This tracking system produces real-time, GPS accurate positioning, from replaceable tethered surface-floating tags. With real-time access to accurate positional data, tagged sharks can be located anytime and anywhere, tags can be retrieved from sharks before they leave the estuary, and tags swapped when batteries run low. This allows fine-scale positional data to be collected for as long as the sharks remain in their spawning area. This presentation will explain how this new tracking method has enabled the identification of movement patterns of adult rig.

Bio-logging Symposium poster September 2014



A New way of tracking sharks

Tracking shallow water elasmobranchs using mesh-networking digital radio devices

NIWA Taihoro Nukurangi

The University of Auckland Faculty of Science

Peter de Joux and Warrick Lyon*
warrick.lyon@niwa.co.nz

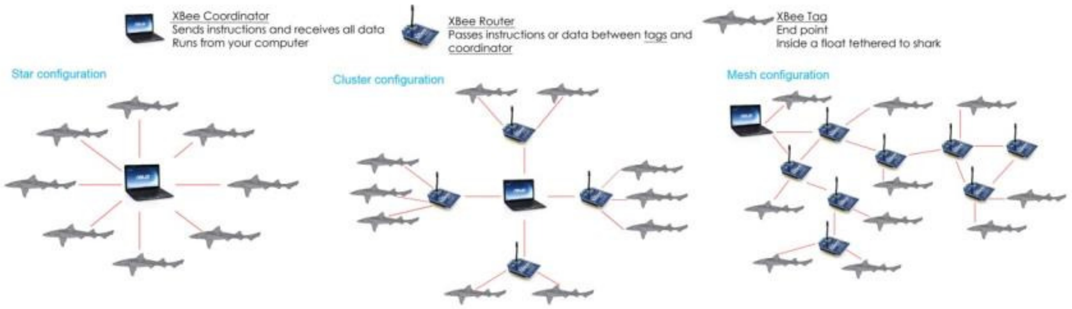
National Institute of Water & Atmospheric Research, Wellington, New Zealand

Introduction

No more sitting in small boats for 36 hours following a shark around your harbour. No more sleepless nights hoping your mooring hasn't drifted away in a storm with all your data still on it. This tracking system uses a network of RF (radio frequency) modules called XBees to immediately pass tagged rig fine scale positional data from tag to a router and to your coordinating computer on land.

Methods

To track rig (*Mustelus lenticulatus*) an RF-network needs a Coordinator, Routers (optional), and end points (Tags). Using a Star, Cluster or Mesh configuration of XBees, a Coordinating XBee (operating from your Field Station or office computer) collects the live positional data from XBee tags tethered to and floating on the surface behind your shark. The positional data are passed from the tag to a router to another router and so on until they reach the Coordinating computer where your data are securely saved.



A shark tag consists of a transmitter (XBee), a microprocessor (Arduino Fio), a GPS receiver (UP501), a battery (Lithium ion) all housed in a small float tethered to your shark. The Routers consist of a transmitter (XBee), a microprocessor (Arduino Fio) and a battery (lead acid), all housed in a floating or terrestrial housing with a solar panel (4.5 W) on top. A Coordinator needs a transmitter (XBee), a microprocessor (Arduino Uno) and a computer.

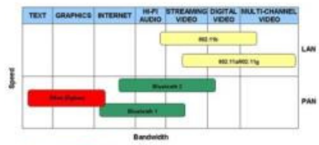
Results

The XBees used in this network operate at a frequency of 2.4 GHz and a transmitting power output of 50 mW resulting in a maximum range of 1.6 km. XBee routers operate for 3-weeks during summer and have a maximum range of 1.6 km. Coordinators also have a range of 1.6 km. Tag life varies with battery power and transmission rate. from 5 hours at a 5 second transmission interval to 13 days at a 5 minute transmission interval. Tag size varies and depends on the size of rig..Neonates have a 34 gram tag and mature rig 70 - 135 grams. XBee data transfer capabilities are different from other wireless standards (Bluetooth and LAN) running at a slower speed and lower bandwidth. An XBee network has low power consumption, is low cost, is flexible and self-healing, allows hundreds of tags and routers, is simple to deploy, has high security, can be used globally, and has product interoperability with other RF module suppliers.

Rig size range (TL)	Life stage	Expected rig weight range (g)	Tag weight (g)	Battery power (mAh)	Tag life @ transmission interval 5 seconds	5-6 minutes**
30 – 55 cm*	Neonate	105–635	34	400	5 hours	18 hours
56 – 80 cm*	Immature	710–2080	45	850	10 hours	44 hours
81 – 90 cm	Mature	2160–3030	70	2000	1 day	4.3 days
91 – 100 cm	Mature	3135–4235	135	6000	3 days	13 days
101+ cm	Mature	4370+	135	6000	3 days	13 days

* Neonate and maturity measurements from Francis and Mace (1980) and Francis and Francis (1992)
** 5 minute transmission rate involves tag going to sleep between transmissions

XBee rig tag details



Wireless standards

Discussion

XBees are part of the ZigBee suite of wireless communication protocols that use small, low-power digital radios for personal area networks. These networks can be built as star, cluster or mesh forms to allow communication across your sampling area. This type of radio communication is most widely used in home automation and electricity smart-meters. Different technologies can be used to track different shark traits. This system works well with rig in Porirua harbour because both basins are very shallow, max 2.5 m deep. The network works well because the estuary is contained. In these shallow esuarine waters managing a tethered float becomes a possibility. Pop-off-archival tags (PAT) have poor spatial accuracy ~60 - 180 km (Hammerschlag et al. 2011). PAT tags can not compete against the small scale high resolution data from XBee tags. Satellite-linked tags (SPOT) tags have higher positional resolution >250 m (Hammerschlag et al. 2011) but are not accurate enough to follow an elasmobranch around an estuary. XBee tags using an AUS$60 GPS receiver have high enough spatial accuracy (95 % of positional readings within 12 m of tag, n=330) to track any elasmobranch around a shallow water estuary.

References

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Router working range ~ 800 m radius
XBee router
Rig