NIWA
Taihoro Nukurangi

MARINE MIGRATION OF THE LONGFIN TUNA HEKE

Identifying migratory pathways and understanding tuna behaviour during migration

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IMPORTANCE OF TUNA TO MĀORI

Aotearoa-New Zealand's iconic longfin eel (*Anguilla dieffenbachii*) is the largest and longest lived of all the freshwater *Anguilla* eel species. This species has significant cultural value to Māori and is considered taonga (treasured). Māori well-being has long relied on the sustainable use, conservation and management of freshwater resources including tuna. The ongoing declines in the distribution and abundance of this taonga species impacts on Māori identity.

This project seeks to fill one of the longest-standing gaps in our knowledge of longfin tuna – where they spawn (breed). This will improve our understanding of the risks to the long-term sustainability of the longfin tuna population and help Māori and other resource management agencies to develop sustainable and resilient strategies for ensuring the ongoing survival of longfin tuna.

No-one has yet successfully tracked adult tuna to their oceanic spawning habitats, but based on previous investigations, the spawning grounds for longfin tuna are thought likely to be somewhere near New Caledonia and Fiji. Recent advances in tags used for tracking and, given Aotearoa-New Zealand's proximity to where we think the longfin tuna may be spawning, raises the likelihood of us being able to successfully track tuna all the way to their spawning habitats.

TUNA LIFE CYCLE

After spending most of their life in our freshwater streams and lakes, the eels begin a long journey downstream to the ocean and leave New Zealand's shores to fulfil their final objective in life, breeding. However, where the longfin tuna travel to after leaving our shores remains a mystery.

Ongoing declines in the distribution and abundance of this taonga species require robust life cycle information to develop effective management and conservation strategies. Identifying migratory pathways and understanding tuna behaviour during their ocean migration is crucial to understanding the potential risks to longfin tuna.

Marine stage knowledge and gaps

To date, the larvae of the New Zealand longfin eel have never been captured, so, our knowledge of likely spawning areas for this species is limited to data from direct tracking of migrating tuna heke.

Anguilla dieffenbachii are endemic to New Zealand and classified as Endangered under the International Union for Conservation of Nature Red List which classifies species at high risk of extinction. They were the first *Anguillid* species to be tracked during their ocean migration using pop-up satellite archival tags (PSATs). Following that initial study that tracked the movement of four female longfin tuna off the coast of New Zealand's South Island, a further 13 have been tagged and tracked across two separate studies in 2005 and 2010.

These studies indicated a general northward migratory trajectory from their release point on the east coast of New Zealand's South Island towards the North Fiji Basin between Fiji and New Caledonia, however their final breeding destination remained unknown.

Eggs

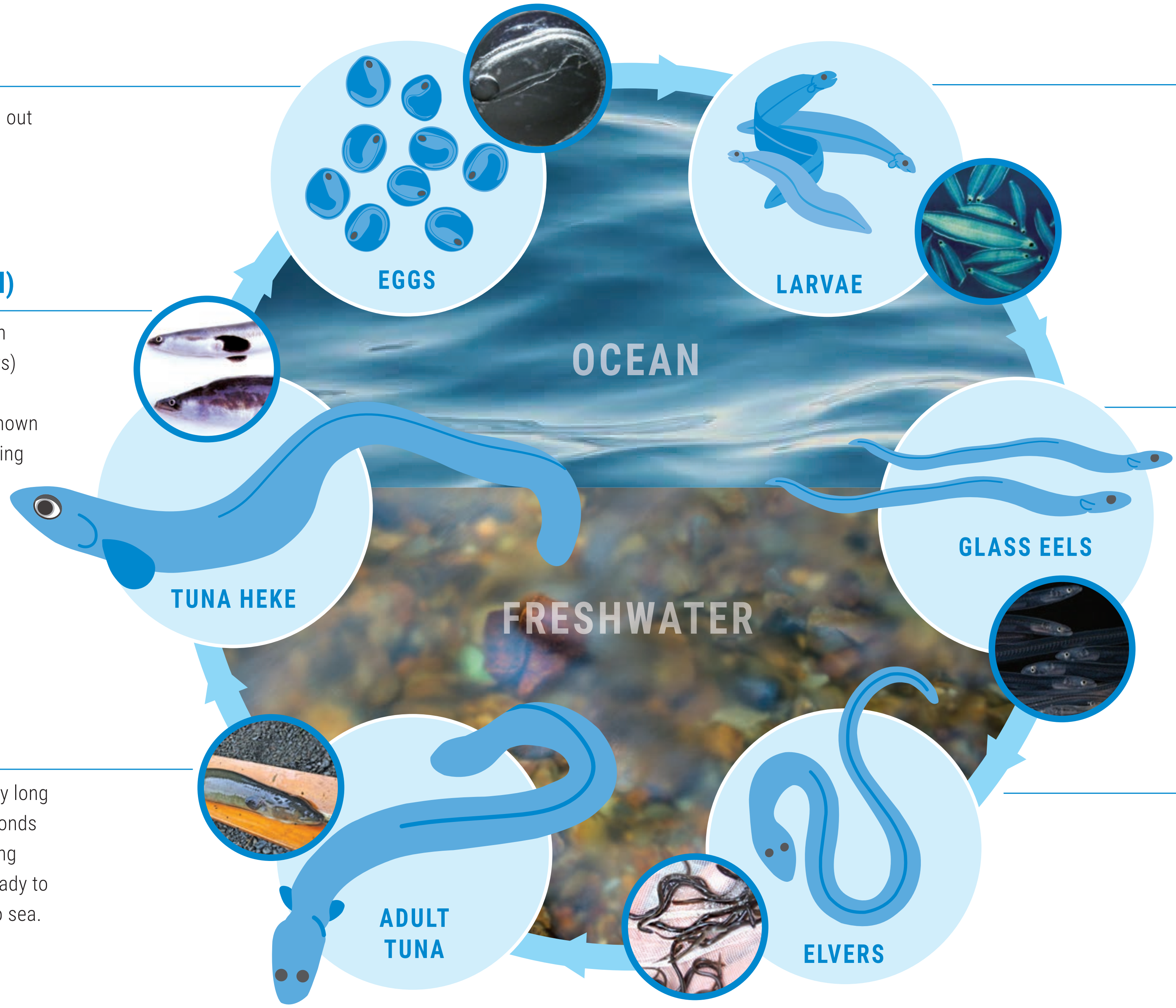
The tuna starts its life as an egg out in the Pacific Ocean.

Tuna Heke (migrant eel)

After a long life in freshwater (on average between 11 and 52 years) tuna start to change and stop feeding. This is when they are known as tuna heke or "silver eels". During rainy nights in autumn (and sometimes spring) they begin their long migration (or journey) to the Pacific Ocean where they spawn and are thought to die.

Adult tuna (feeders)

The adult tuna live for a relatively long time in rivers, lakes, wetlands, ponds and streams, eating and preparing themselves for when they are ready to begin their migration back out to sea.



Larvae

They hatch at sea into see-through (transparent), leaf-shaped, larvae called *leptocephalii* and spend between 9 to 12 months drifting on ocean currents which bring them back to Aotearoa.

Glass eel

When they reach the seabed near Aotearoa (continental shelf) they change shape and turn into colourless eels called glass eels, about 60-70 mm long. In early spring they move into estuaries, rivers and streams where they rest to get used to their new freshwater environment.

Elvers (juvenile eel)

After several weeks, they begin to turn brown (gain pigmentation) and begin their journey as an elver and head upstream. Keep an eye out in your local waterway during summer for elvers travelling up your stream.

Tuna are the most widespread freshwater fish in Aotearoa. They also have an unusual life cycle which sees them travelling between the sea, estuaries and freshwaters.

ABOUT THE PROJECT

The objective of this project was to tag and track longfin tuna during their ocean migrations to confirm the migration pathways, fate and the location of their spawning grounds.

In May 2019 the project team attached PSATs to twenty female migrant longfin tuna. The tuna heke were captured and released from two separate locations, ten from the Waikato River on the west coast of the North Island and ten from Te Waihora on the east coast of the South Island. The tags collect information on the depth that the tuna swim and the water temperature around them. When the tags are released from the eels, they transmit their location and the data via satellite.

The tags were pre-set to pop-off from the tuna between five and eight months after they were tagged and released (October 2019 to January 2020).

Te Waihora

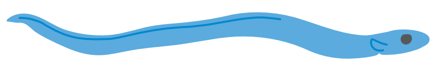
Port Waikato

THE TAGGING AND RELEASE

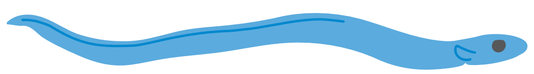
This study was carried out with approval by the NIWA Animal Ethics Committee (AEC201) and with the requirements of section 83 of the New Zealand Animal Welfare Act 1999.

The tuna heke

Ten tuna heke migrant female were captured by commercial or indigenous eel fishers from the lower Waikato River on the west coast of the North Island of New Zealand and 10 from Te Waihora on the eastern coast of the South Island of New Zealand during April and May 2019. Captured eels were transferred to holding tanks and held at ambient temperatures for up to two weeks prior to tagging and release.



The median total length and weight of the *Waikato* eels was 1.12 m (range 0.89-1.29 m) and 4.4 kg (range 2.1-6.0 kg).



The *Te Waihora* eels were on average larger, with a mean length of 1.38 m (range 1.20-1.49 m) and mean weight of 7.8 kg (range 6.0-10.5 kg).

Pop-up archival satellite tags

All eels were tagged with Microwave Telemetry X-tag pop-up archival satellite tags (PSAT). These tags measure 12 cm long with an 18 cm antenna, have a maximum diameter of 3.3 cm, and weigh 46 g.

Release occurred either on the same day (Waikato eels) or the day following tagging (Te Waihora eels). The Waikato eels were released at dusk in the estuary of the Waikato River approximately 3 km from the river mouth. The Te Waihora eels were released mid-morning in the estuary of the Rakaia River approximately 2 km from the river mouth.

Sensors in the tag collect and archive data on pressure (depth), water temperature and light irradiance at two minute intervals and can be fully retrieved if the tag is physically recovered. A limited subset of the stored data is transmitted via the Argos satellite system after the tag surfaces, and the proportion of transmissible data that is received by Argos varies depending on environmental conditions and battery power at time of transmission. Data transmitted to the Argos system include daily minimum and maximum light levels, depths and temperatures, and time series of depth and temperature at 15 minute intervals for deployments up to four months and 15-30 minute for deployments of 4-8 months.

All tags were pre-programmed to release after five to eight months. However, the tags also have in-built fail-safe mechanisms that should trigger if the pressure remains constant for a given period (two days) or exceeds a threshold depth (>1250 m) for greater than 15 minutes. If a tag becomes detached from an eel prematurely and starts drifting at the surface, the constant pressure mechanism results in a delay of two days before data transmission occurs creating uncertainty over the precise pop-up location of the tag.

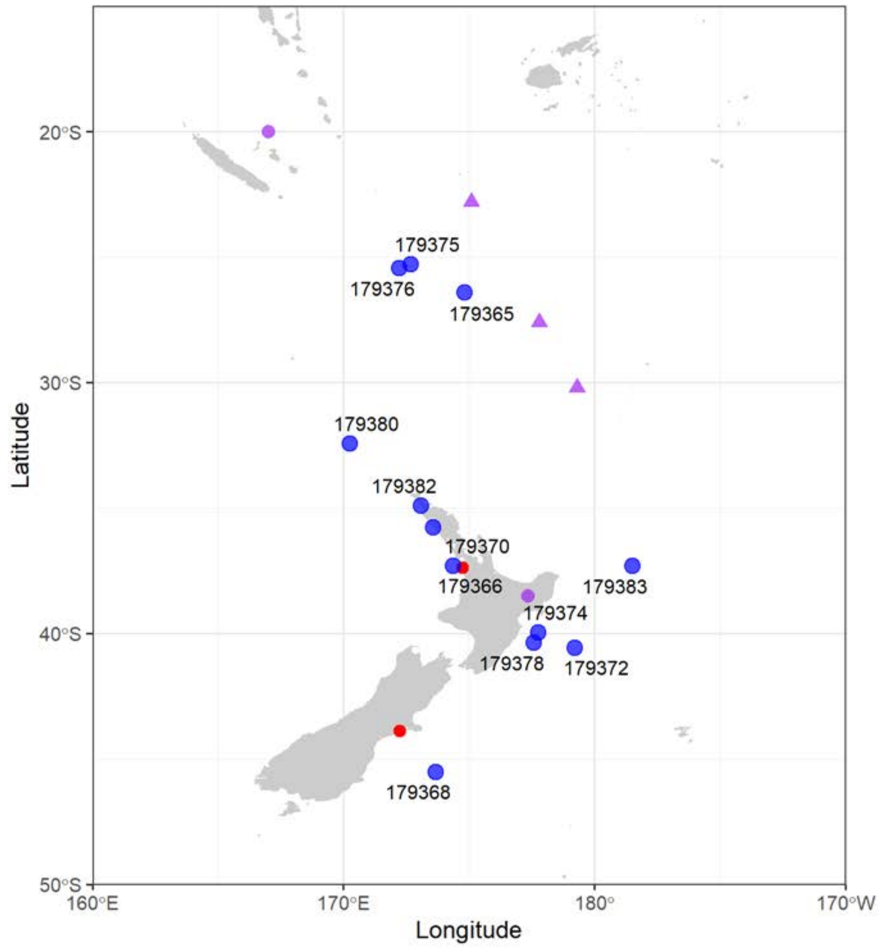


Figure 1: Map showing the location of the study area. Red dots mark the two 2019 release points at the mouth of the Waikato River (west coast) and the Rakaia River (east coast). The blue dots indicate the end positions of tags from this study. The purple symbols indicate the end positions of tags from the previous studies in 2005 and 2010.

DATA RECOVERY

Data were recovered from twelve of the twenty tags deployed giving an overall tag return rate of 60%, which is relatively low compared to similar studies with other *Anguillid* species.

Eleven of the twelve tags sent data back via the ARGOS system, while one tag (179382) was discovered on Ninety Mile Beach in Northland and returned to the PSAT supplier for retrieval of the full data set.

No tags reached their programmed release date, with the average deployment duration being 35.6 days (range 12 to 86 days). Most of the twelve tags returned a high proportion of data (>90%), but one tag returned less than 1% of its data and another only 15%.

SUMMARY OF FINDINGS

A pause in the journey

All eels displayed evidence of a temporary halt in migration within the estuaries where they were released after tagging. This delay ranged from three to twelve days with a median of five days across all eels. Eels released in the Waikato River estuary averaged a slightly longer delay (seven days) before entering the ocean compared to those released in the Rakaia River estuary (five days).

Predation

Predation is the killing of one living organism by another for food. Of the twelve tags that returned data, four show clear signs of predation and a further two were likely predated. One tag returned insufficient data to determine its fate, but the remaining five released prematurely with no explanation. We can only speculate as to the fate of the remaining eight tags for which no data have been returned.

A key finding was the evidence for high levels of marine predation of longfin tuna heke. Likely predators included marine mammals, sharks and possibly tuna fish. While most predation occurred close to Aotearoa on its continental shelf, at least two eels were predated by whales in the open ocean. See figures 5–7 on pages 14–15 for more.

The high predation rate highlights the importance of understanding the risks in this crucial life stage for better freshwater management strategy decision-making.

Migration pathway and destination

The 7-day average pathway suggests eels are following relatively direct migratory routes between their release and pop-off locations (red lines in Figure 2).

The east coast eels appear to be following a pathway in a north easterly direction parallel to the New Zealand coast. Based on previous results we would expect a shift to a more northerly direction once these eels pass the East Cape of New Zealand. The west coast eels follow an initial north westerly trajectory close to and parallel with the New Zealand coast until they pass Cape Reinga.

The two eels that travelled the furthest both showed a similar shift to a more northerly migration into the South Fiji Basin, although it appears there could be some wandering once in open ocean. Like the results of the 2010 study, these tags indicate a convergence of eels departing from both the east and west coasts of New Zealand, strengthening the evidence indicating a spawning location in the North Fiji Basin between New Caledonia and Fiji (or beyond).

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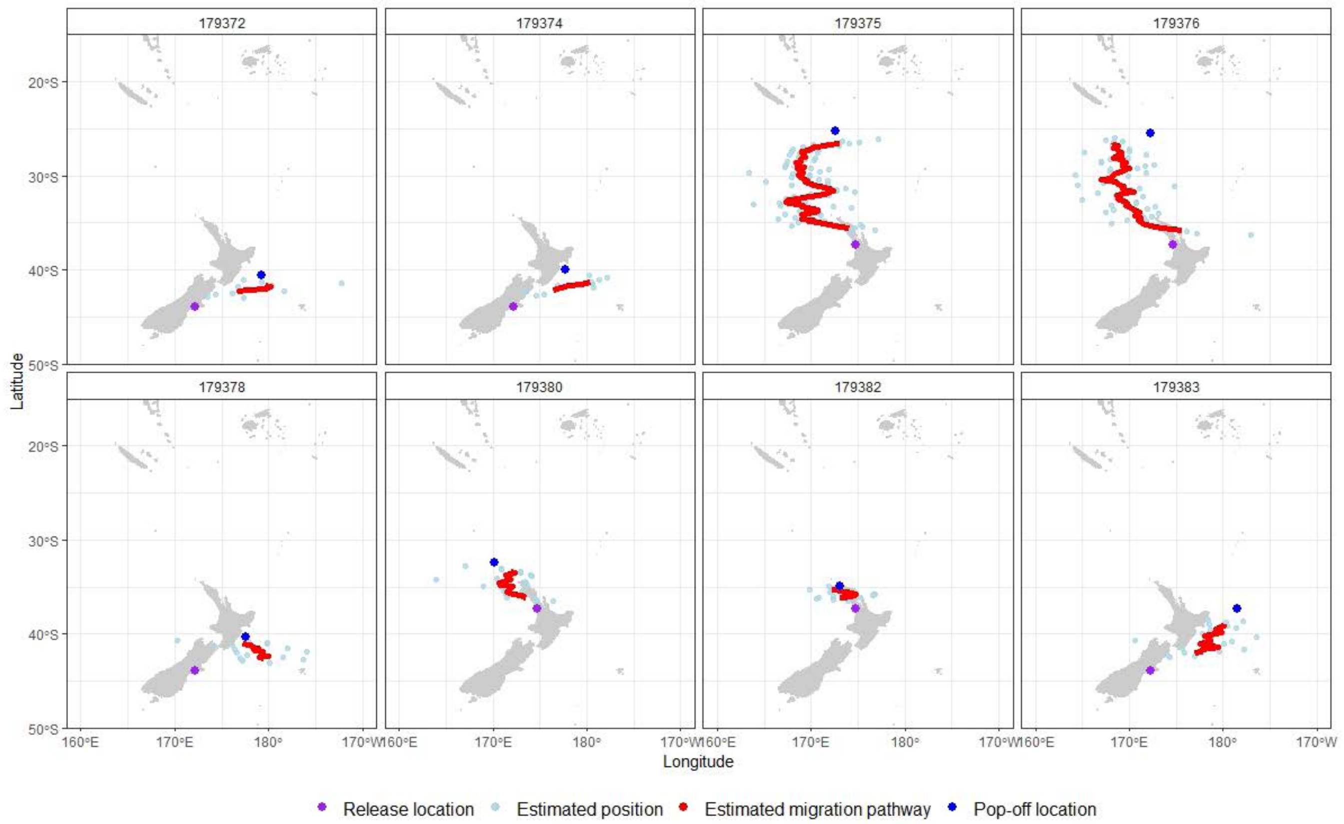

Figure 2: Reconstructed migratory pathways for eight of the tagged eels with sufficient data. Daily position (light blue dots) is estimated by using the timing of diel vertical migrations to determine approximate timing of sunrise and sunset and, hence, geographical location. 7-day averages (red dots) are used to smooth out uncertainties in these daily estimates to give an approximation of the overall migratory pathway.

24-HOUR VERTICAL MIGRATION (Diel vertical migration)

What is DVM

Diel vertical migration (DVM) is a pattern of movement during marine migration that some species, including *Anguilla* eels, undertake.

DVM involves regular vertical migrations over a 24-hour period. Eels start ascending closer to the ocean surface upon sunset but commence descent to deeper water prior to sunrise.

Eight eels in this study showed clear evidence of DVM, commencing between four and ten days after their release. The median DVM period was 20.8 days, with a range from 11 to 72 days.

Depth and dive rate

Mean nighttime swimming depth across all eels was 160.8 m but varied between individuals from 111 m to 194 m. Mean daytime swimming depth across all eels that displayed DVM was 659.0 m, varying from 414 m to 752 m.

Several of the eels displayed occasional dives to greater than 1000 m. These were generally one-off events and followed by a return to the more typical DVM pattern. The mean dive rate across the DVM period (16 days) was 5.3 m/minute, with a maximum rate of 19.2 m/minute. The mean ascent rate was 5.4 m/minute, with a maximum rate of 12.6 m/minute.

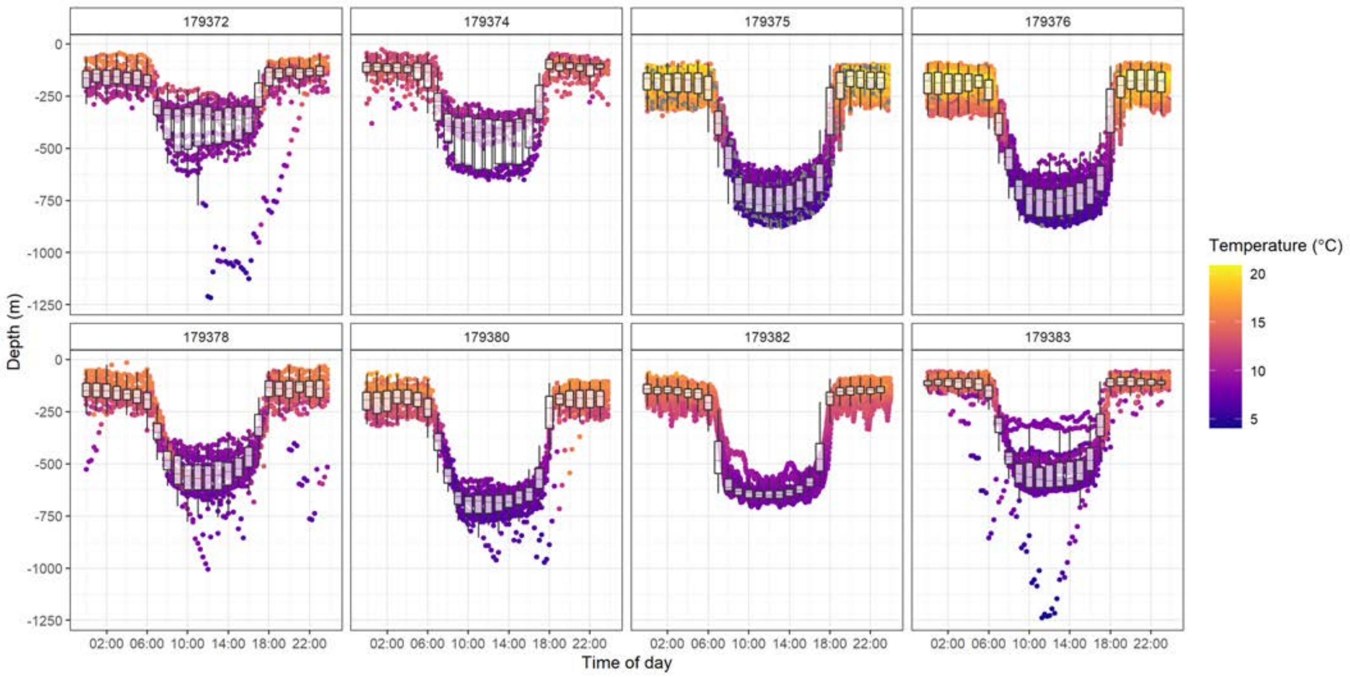

Figure 3: Depth and temperature data for the eight eels that demonstrated sustained periods of DVM. The boxes show the hourly median (midline), lower and upper quartiles (lower and upper limits of the boxes), and extent of any outliers (whiskers) throughout the period of DVM. Points show depth coloured by temperature. Grey points occur where the corresponding temperature data is unavailable.

Temperature

Mean nighttime water temperature was 15.1°C, but also varied between individuals from 12.5°C to 16.7°C. Daytime water temperatures averaged 7.9°C and varied between individuals from 7.1°C to 9.4°C. Mean nighttime water temperatures increased with increasing duration of DVM as the tuna progressed north towards warmer tropical waters. In contrast, mean daytime water temperatures decreased with increasing duration of DVM, which was driven by the trend towards greater daytime swimming depths.

Moon phases

Tuna showed a clear pattern of increased nighttime swimming depth during the period of increasing moon illumination. Between the new and quarter moon phase the eels maintained a nighttime swimming depth around 150 m deep. As moon illumination increased from the quarter to full moon phase the nighttime swimming depth progressively increased to be approximately 100 m deeper (250 m) under full moon conditions.

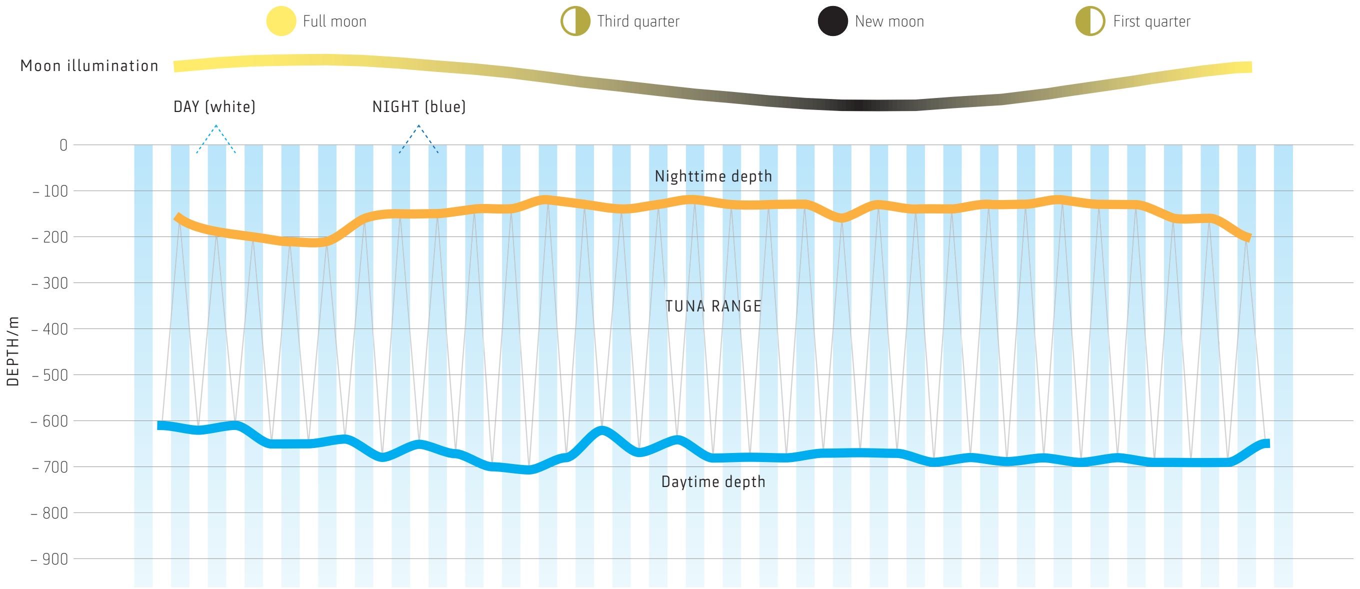

Figure 4: This figure illustrates how tuna behaviour responds to light. Eels move deeper during daylight and shallower when it is dark. Eels also stay further from the water surface at night during full moon (brighter) compared to new moon (darker). It is thought this strategy helps avoid predators and may control how fast the eels mature. Find out more in the DVM summary below.

DVM summary

Various suggestions have been made to explain DVM, mainly predator avoidance and control of maturation (how fast species mature).

- There is now strong evidence to show that the dive and ascent phases of DVM are closely linked to the dawn and dusk periods showing that light intensity is important for behaviour.
- The move to deeper water during daylight is considered a predator avoidance strategy, with the low light at greater depths providing protection from visual predators.
- The evidence emerging across multiple species of increased nighttime swimming depths during periods of greater moon illumination further supports this idea of anti-predator behaviour.
- The purpose of the daily vertical migration to shallower waters remains less clear. It may relate to body temperature and control of maturation.

SUMMARY DATA

Individual tag results showing predation and suspected predation

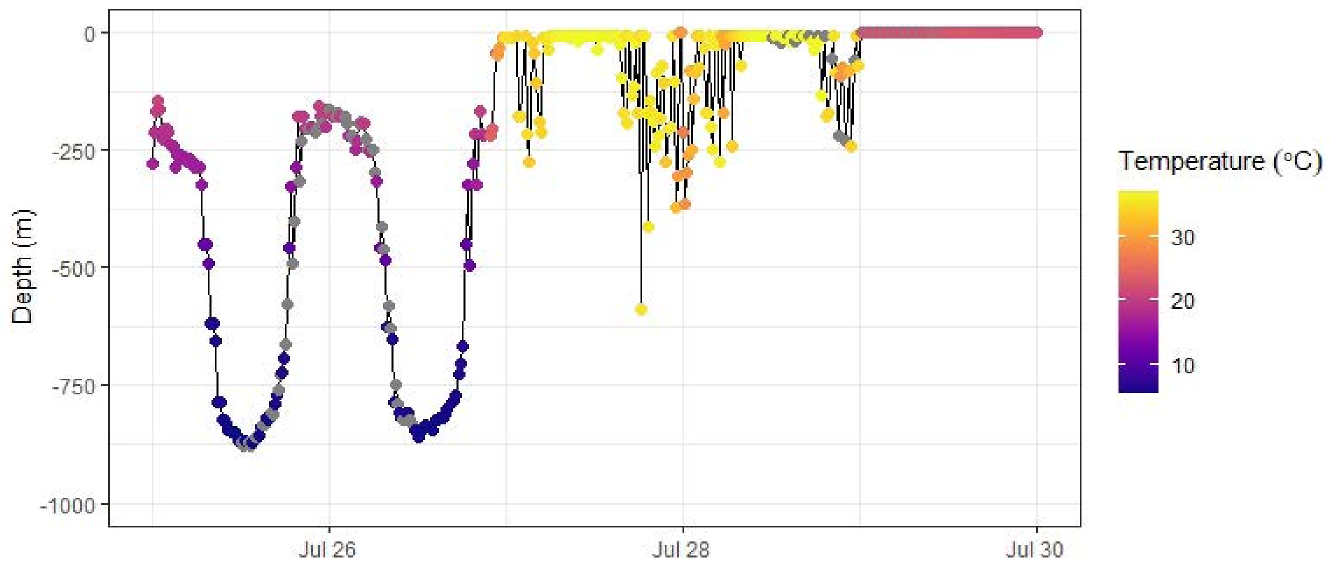

Figure 5: Tag 179375 – predation
This eel was predated on the night of 26 July while relatively close to the surface. The temperatures (c.37C) post-predation indicate it was eaten by a mammal. The depth profile after predation shows that of the predator and indicate regular (c.55min) deep dives consistent with a whale.

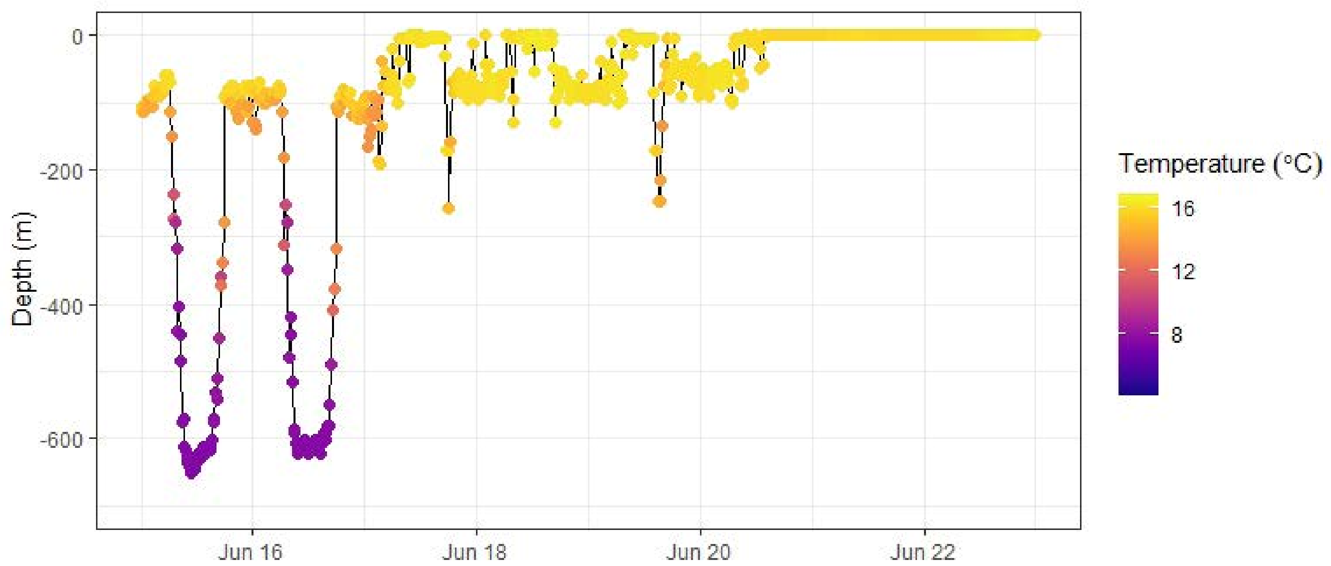

Figure 6: Tag179383 – predation
This eel was predated in the early hours of 17 June close to the surface. The body temperature of the predator is slightly warmer than the surrounding water. The predator dive profile shows a distinct day/night pattern, spending days close to the surface and nights at around 100 m with occasional deep dives. This behaviour is similar to that observed in southern bluefin tuna.

Tag	Release location	Pop-off location °S	Pop-off location °E	Pop-off date	Deployment duration (days)	% data returned	Distance travelled (km)	Average swimming speed (km day-¹)	Max. depth (m)	Min temp (°C)	Max temp (°C)	Fate
179365	Waikato River	26.415	174.821	2019-07-21	76	0	1217	16.01	683	NA	NA	Insufficient data
179366	Waikato River	37.293	174.348	2019-05-25	19	99	36	1.87	83	5.8	18.4	Suspected predation
179368	Rakaia Lagoon	45.512	173.653	2019-06-01	17	100	212	12.49	113	9.8	16.7	Suspected predation
179370	Waikato River	35.761	173.552	2019-05-18	12	15	209	17.41	97	14.9	27.8	Clear predation
179372	Rakaia Lagoon	40.559	179.205	2019-06-03	19	100	683	35.97	1216	4.9	16.2	Premature release
179374	Rakaia Lagoon	39.956	177.755	2019-06-02	18	100	632	35.13	1033	5.2	16.4	Premature release
179375	Waikato River	25.28	172.664	2019-07-31	86	87	1357	15.77	877	5.5	36.9	Clear predation
179376	Waikato River	25.431	172.221	2019-07-12	67	95	1347	20.10	877	5.8	35.8	Clear predation
179378	Rakaia Lagoon	40.369	177.569	2019-06-09	25	100	589	23.55	1006	6.5	16.4	Premature release
179380	Waikato River	32.424	170.235	2019-06-02	27	100	687	25.44	974	5.3	19.9	Premature release
179382	Waikato River	34.987*	171.913*	2019-06-13	27	100	367	13.59	1291	2.7	18.1	Premature release
179383	Rakaia Lagoon	37.307	181.493	2019-06-23	39	100	1070	27.44	1237	4.0	16.8	Clear predation

Figure 7: Summary of tag results

PROJECT CONCLUSIONS

- The 60% tag response rate in this study was disappointing compared to studies elsewhere that had typical return rates greater than 75%. The reason for this low return rate is unclear given the common methods between studies and experience of the project team.
- Given the relatively high predation rate, it is also possible that some tags were damaged during predation events and failed to transmit data. Selecting release sites that minimise the duration that eels spend on the continental shelf (e.g. the northern coast of the North Island) may help to reduce the possibility of losses due to predation.
- While the precise location of spawning sites of longfin tuna remains a mystery, we have provided the first evidence of marine predation and have increased the evidence in support of a spawning location in the Fiji Basin given the convergence in this region of eels from both the east and west coasts of New Zealand.

Developing a more detailed understanding of the critical marine life stages of this species is crucial for securing their future status. Our ability to manage the risks to eels during the marine life stages may be limited, but it is essential that we understand the risks arising from future changes to oceanic currents and temperatures, and predator abundance. In the absence of this knowledge our choice of freshwater management cannot account for these additional risks to the species.

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Acknowledgements

We appreciate the support and input provided by Waikato-Tainui and Te Taumutu Rūnanga tribal members in undertaking this project and acknowledge the important role they play in the protection of this taonga in Aotearoa-New Zealand. We also thank the eel fishers Bob Clarke and Clem Smith for their assistance in capturing the eels required for this study and the NZ Eel Processing Company and Mossburn Enterprises for holding captured fish and allowing access to their facilities for tagging. Shayde Flood deserves special mention for his recovery and return of one of our tags from Ninety Mile Beach. Funding for this project was provided by Waikato-Tainui, Mercury NZ Limited, the Royal Society Te Apārangi Catalyst Seeding Fund (CSG-NIW1703), and the NIWA Strategic Science Investment Fund.

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niwa.co.nz/freshwater