Survival and depth distribution of spinetail devilrays (*Mobula japanica*) released from purse-seine catches

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Authors/Contributors:
Malcolm P Francis

For any information regarding this report please contact:

Malcolm P Francis
Principal Scientist
Coastal Group
+64-4-386 0377
m.francis@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
301 Evans Bay Parade, Greta Point
Wellington 6021
Private Bag 14901, Kilbirnie
Wellington 6241
New Zealand

Phone +64-4-386 0300
Fax +64-4-386 0574

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Reviewed by

Reyn Naylor

Approved for release by

Dr Richard O’Driscoll

Executive summary

This study aimed to assess the fate of live released spinetail devilrays (*Mobula japanica*) captured in commercial purse seine fisheries, and to describe their spatial and vertical behaviour. Six rays were tagged with popup archival satellite tags by an observer off northeastern North Island, New Zealand, in January−February 2013. Only four of the six tags reported data, and three of the four rays that provided data died within 2−4 days of release. The fourth ray (tag 115490) provided 82 days of track data before the tag pulled free, washed ashore, and was recovered, enabling the archived data to be downloaded.

Ray 115490 did a large loop to the north of New Zealand soon after release, before returning to near North Cape. It then spent six weeks off the east Northland coast beyond the edge of the continental shelf. The ray apparently stayed within the New Zealand Exclusive Economic Zone for the whole track, i.e. January to March. Spinetail devilrays could potentially travel much greater distances than indicated by the single short track obtained here. Longer tag deployments and a larger sample size are necessary to determine the habitat of spinetail devilrays in the New Zealand region.

Ray 115490 spent most of its time shallower than 100 m, with more time in shallow water during the night (2000–0500 hours NZST) than during the day/twilight (0500–2000 hours): the proportions of time spent in 0–25 m, 25–50 m, and greater than 50 m were 60.8%, 28.4% and 10.9% respectively by night, and 43.5%, 34.3% and 22.2% respectively by day. The median night time depth was 18.5 m and the median day/twilight depth was 28.5 m. The distribution of temperatures experienced was similar by night and day. The ray made periodic, short deep dives. There was no diel pattern in the timing of dives deeper than 75 m, but dives deeper than 100 m were most common at dusk (1600−1900 NZST), whereas dives deeper than 200 m were nearly all made during the day or twilight, with peaks at dawn (0600–0700) and dusk (1700–1900). The ray made three dives deeper than 500 m, and reached a maximum depth of 649 m, which is the deepest dive so far reported for this species. The ray was very active, making almost continuous vertical movements of at least 30–40 m amplitude. However, its vertical behaviour varied considerably through a diel cycle and over the full deployment period. Most days showed movement between the surface and about 40 m, but deeper dives were irregular with some periods having few dives deeper than 200 m (e.g. mid January) and others having many dives deeper than 300 m (e.g. mid March).

The three deaths observed out of four rays released indicate that mortality may be significant. Until further devilrays can be tagged, and a reasonable estimate of mortality of released animals obtained, fishers should be encouraged to release animals from the purse seine net while it is still in the water, rather than after they have been lifted on to the deck, to maximise their chances of survival.

1 Introduction

Two species of rays in the Family Mobulidae are known to occur in New Zealand waters – spinetail devilray (*Mobula japanica*) and manta ray (*Manta birostris*) (Gilbert & Paul 1969, Paulin et al. 1982, Stewart 2002, Duffy & Abbott 2003). Both species have been protected under Schedule 7A of the Wildlife Act (1953) since July 2010. Other species of *Mobula* and *Manta* may also occur in New Zealand waters, at least seasonally as migrants from tropical waters, but their presence has not been confirmed.

Devil and manta rays are caught in purse seine fisheries worldwide (Bailey et al. 1996, Romanov 2001, Molony 2005). In New Zealand, spinetail devilrays and manta rays have been reported caught by the skipjack tuna (*Katsuwonus pelamis*) purse seine fishery operating mainly in January–March (Paulin et al. 1982). Skipjack are caught mainly off the east coast of North Island between East Cape and North Cape, and to a lesser extent off west Northland and North Taranaki Bight (West 1991, Kendrick 2006). They prefer subtropical waters having surface temperatures of 19–22 ^{o}C, with most catch taken over seabed depths less than 200 m (Habib et al. 1980, 1981, West 1991). Spinetail devilrays comprise most and possibly all of the “manta” ray bycatch in New Zealand purse seine fisheries, but the true manta ray may also be caught (Francis & Lyon 2012, Jones & Francis 2012).

The protected status of spinetail devilrays means that their capture and mortality should be avoided or minimised. A companion study reviewed the incidence of devilray captures in the New Zealand purse seine fishery, and investigated methods for reducing captures and facilitating the live release of rays that are caught (Jones & Francis 2012). In the present study, electronic tags were placed on six devilrays caught by purse seine vessels in an attempt to estimate the survival of released animals. The aim of this study was:

“To assess the fate of live released protected rays captured in commercial purse seine fisheries and describe their spatial behaviour”

2 Methods

Popup Archival Transmitting (PAT) tags were used to determine the fate of devilrays released into the sea from tuna purse seine vessels. PAT tags are electronic devices that record temperature, depth and approximate location (estimated from the times of dawn, dusk and midday using on-board light sensors). After a pre-programmed period, or after experiencing constant depth for a pre-determined time, the tag releases itself from the ray, floats to the surface, and transmits summaries of the collected data to an orbiting Argos satellite. The data are then delivered to the tag owner by email or by downloading them from the Argos website.

Six Wildlife Computers miniPAT popup tags were provided to a Ministry for Primary Industries (MPI) observer deployed on skipjack tuna purse seine vessels to attach to spinetail devilrays. Our intention was to estimate the survival of devilrays subjected to normal fishing practices, so the observer was instructed not to make any special effort to treat the rays better than the crew would normally have done. Only rays that were lifted in a brail net and brought on to the deck were tagged, because rays that were released from the purse seine net while still in the water were expected to be in excellent condition and survive. Rays were classified into four predicted survival categories using a series of behavioural and physical criteria (Appendix A). Only rays in the low, moderate and high survival categories were eligible for tagging.

Devilrays were tagged in the central, thick part of the wing musculature. The intention was to embed the anchors deeply in the muscle to provide secure attachments, and to avoid the body cavity and thinner parts of the wing near the margins. Two nylon tag anchors were used: a primary “umbrella” anchor with eight plastic barbs, some of which were covered with a dacron sleeve to promote tissue healing around the anchor; and a secondary “tie-down” anchor to hold the tag close to the ray’s body and reduce tag movement (Figure 1). This attachment method has been used successfully to track *Mobula japanica* for up to 188 days in the Gulf of California (Newton et al. 2010, Croll et al. 2012). Rays were measured (disk width DW and disk length DL), sexed (only possible if the pelvic fins were visible) and their weight was estimated. The behaviour of the ray following release was recorded, as were the location, sea surface temperature (SST) and seabed depth at the point of release. A tissue sample was taken for subsequent DNA analysis.

Figure 1: MiniPAT tag used for spinetail devilrays. Top: Tag showing the tag body (left) and tether (right). The main "umbrella" anchor with white dacron sleeves on some barbs is at the right hand end of the tether, and the secondary "tie-down" anchor is at the bottom of the yellow tubing. Bottom: Enlargement of two umbrella anchors showing eight nylon barbs (minus the Dacron sleeves).

PAT tags have been used frequently to estimate post-release mortality in other large marine species (Domeier et al. 2003, Moyes et al. 2006, Campana et al. 2009b, 2009a). A tag can ‘detect’ death by monitoring vertical movement as measured by its depth (pressure) sensor.

If no vertical movement is detected during a pre-programmed period (3 days in the present study), the tag releases itself by sending a current though the metal pin that connects the tag to its tether, and the electrolytic reaction with seawater dissolves the pin in a few hours. This allows the tag to float to the surface where it begins transmitting data to a satellite. Dead rays are expected to sink to the seabed, thus producing a record of constant depth. If a ray dies over deep water, it's tag will release itself through a depth-activated safety mechanism as it sinks past about 1800 m depth. Live rays are expected to swim continuously and at various depths, so the constant-depth auto-release will not activate on living rays, and the tag will not pop up until the prescribed end-date for the experiment. Depth data transmitted in the day(s) before tag pop-up can confirm whether the ray survived until that time.

Depth and temperature data collected by miniPAT tags were available in two formats: as time series collected at either 5 minute or 10 minute intervals and transmitted via satellite (hereafter called transmitted data), or as time series collected at 10 minute intervals and downloaded from recovered tags (archival data). Transmitted data series were not always complete because not all transmitted messages were received by the Argos satellite and decoded correctly.

Vertical movements to depths greater than 75 m, 100 m, and 200 m were classified as 'dives' using the R package *diveMove* (Luque 2014).

Daily positions were estimated from ambient light data stored on miniPAT tags using proprietary software from Wildlife Computers (WC-GPE: Global Position Estimator Program Suite, www.wildlifecomputers.com). Daily records with poor dawn/dusk light level curves were excluded from the analyses. Most probable tracks were refined by matching tag-measured SST with remotely-sensed SST data using unscented Kalman filtering (*UKFSST*) (Nielsen et al. 2006, Lam et al. 2008). *UKFSST* models were fitted with or without latitude bias, longitude bias, SST bias, solstice error variance (accounts for greater error around the equinoxes), and last position not known accurately (fix.last = false).

3 Results

Six spinetail devilrays were tagged by an observer from purse seine vessels off northeastern North Island in January−February 2013 (Table 1). Four were tagged northeast of Great Barrier Island and two near Poor Knights Islands. All rays were caught and released near the edge of the continental shelf (approximately defined by the 200 m isobath) (Figure 2). The devilrays measured 110−140 cm DL and 215−265 cm DW. The rays were all classified as having high or moderate−high survival probability (Appendix 1). Only three rays were sexed, and they comprised two males and one female. Male *Mobula japanica* mature at about 200−210 cm DW, with females perhaps maturing at a slightly larger size (Notarbartolo-di-Sciara 1988, White et al. 2006b), so all the tagged rays were probably mature.

Table 1: Spinetail devilray tagging details and number of days tracked. SST = sea surface temperature (^{o}C).

Tag number	Tagging location	Tag latitude	Tag longitude	Date deployed	Days tracked	SST	Depth (m)	Disk length (cm)	Disk width (cm)	Sex	Weight (est.)	Survival class
115487	NE Great Barrier Is	35.7450	175.5033	10 February 2013	4	22.4	179	110	215	M	90	Mod-High
115488	NE Great Barrier Is	35.7443	175.4870	10 February 2013	4	22.7	187	140	240	M	100	Mod-High
115489	NE Great Barrier Is	35.7772	175.5550	11 February 2013	2	22.5	215	130	260	?	110	Mod-High
115490	E Poor Knights Is	35.3940	174.9862	10 January 2013	82	21.0	300	140	260	?	130	Mod-High
115491	N Poor Knights Is	35.2898	174.6183	11 January 2013	No data	23.0	141	130	260	F	140	Mod-High
115492	NE Great Barrier Is	35.8258	175.6208	12 January 2013	No data	22.0	240	130	265	?	130	High

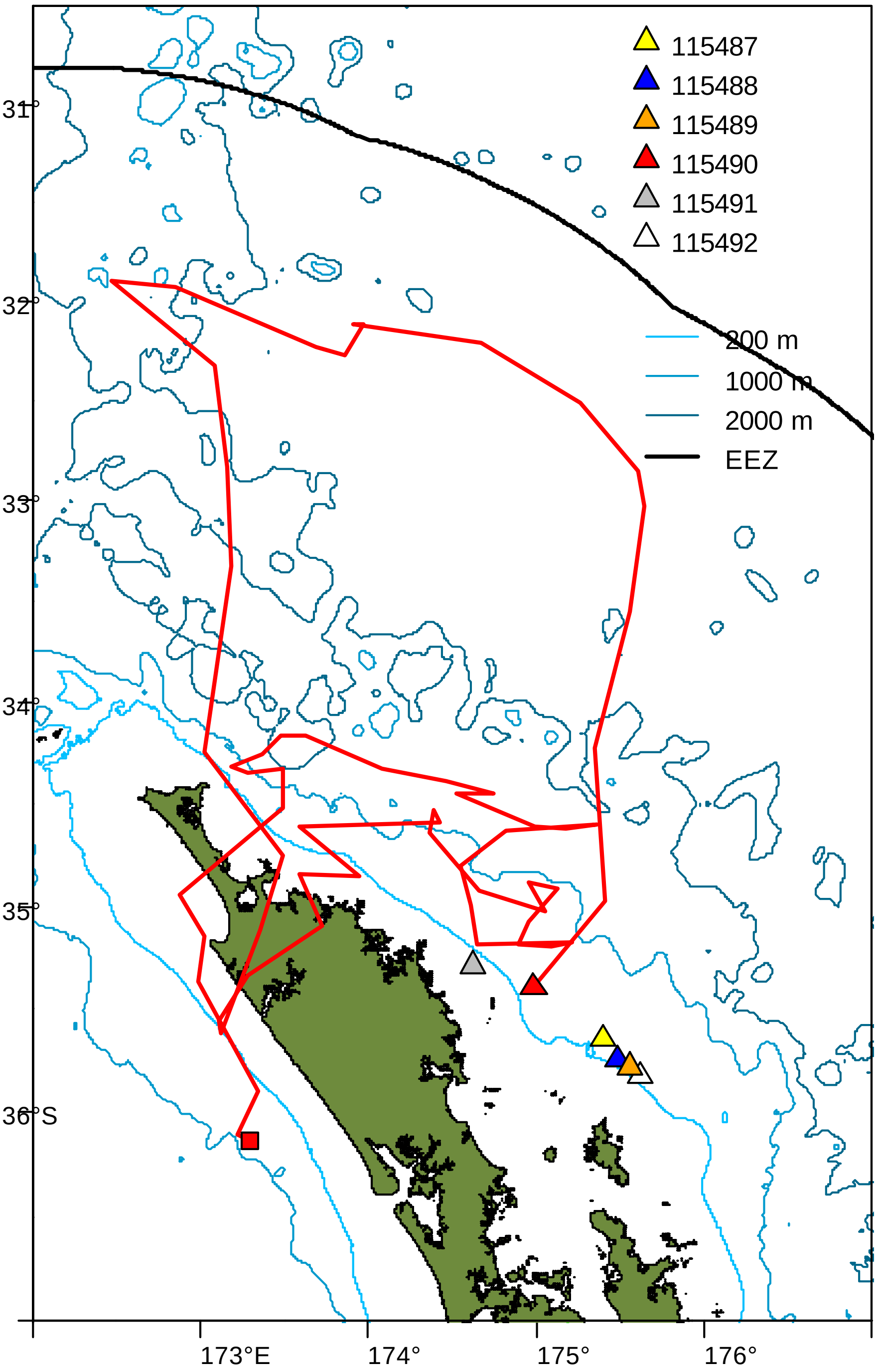

Figure 2: Release locations of six tagged spinetail devilrays and reconstructed track for one of them. Triangles indicate release locations off northeastern North Island. For ray 115490, the estimated track and tag popup location (square) are also shown (see text for further details). Apparent movements over land reflect insufficient location fixes to show the actual track around the land.

Only four of the six tags reported data (Table 1). Three of the four rays that provided data died within 2−4 days of release. The fourth ray (tag 115490) provided 82 days of track data before the tag pulled free, washed ashore at Taemaro Bay (34.945 ^{o}S, 173.574 ^{o}E) near Mangonui, and was recovered, enabling the archived data to be downloaded. A detailed analysis of the data from the four tags is presented below.

Tag 115487

For the first 3.5 days after release, this ray spent most of its time (90.4%) between the surface and 50 m, and nearly all of its time shallower than 75 m (98.9%) (Figure 3). It made three short dives to depths greater than 100 m, reaching a maximum recorded depth of 142 m. On the fourth day after release, the ray sank rapidly to a depth of 1753 m, and was likely dead at that stage. The tag did not pop up after three days at a constant depth as expected; instead it remained on the seabed for three weeks before finally rising rapidly to the surface. The delay in popup may have been a result of the ray lying upside down on the seabed, thus trapping the tag underneath its body until it had decayed or been scavenged sufficiently to release the tag. Thereafter, the tag drifted at the surface for about five months, punctuated by regular vertical movements to depths of 50−150 m, and one major 1.25-day plunge to 1800 m, between mid May and mid July (Figure 3). The tag continually returned to the surface between these vertical excursions. Investigation of the data by Wildlife Computers revealed no evidence of problems with the depth sensor, and the depth data were corroborated by temperature data[1], suggesting that the depth data are valid. The vertical movements were presumably caused by marine animals (fish or mammals) grasping or ingesting the tag, carrying it down in the water column, and then releasing or regurgitating it.

Tag 115488

For the first 4.5 days after release, this ray spent most of its time (97.2%) between the surface and 50 m, and nearly all of its time shallower than 75 m (99.8%) (Figure 3). It made one short dive to 152 m, 1.25 hours after release. On the fifth day after release, the ray sank rapidly to a depth of 1830 m, and was likely dead at that stage. The tag returned to the surface without delay, indicating that the depth-activated safety release had severed the tether.

Tag 115489

The depth and temperature records for this tag were very similar to those of tag 115487 (Figure 3), and they are interpreted in the same way (see above). This tag provided no depth data for the first 1.75 days after release, and by 2.1 days the ray had descended to 1735 m, presumably dead, where the tag remained for 3.5 weeks before popping up to the surface. The subsequent period of drifting at the surface was punctuated by multiple vertical movements in May−June, including a 1.3-day dive to 1710 m.

Tag 115490

Continuous vertical movement of this tag for 82 days following release indicated that the ray survived for 2.7 months before the tag came free prematurely on 2 April 2013 (it was programmed to pop up in mid August 2013), probably because of failure of the tag anchors. The tag subsequently washed ashore where it experienced extremely high temperatures while resting on a sandy beach (Figure 3). This ray appears to have been behaving normally during the period of tag attachment, and so the archival data downloaded from the recovered tag were analysed in detail to provide information on its horizontal and vertical movements, and the environmental temperatures experienced.

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[1] Vertical movements in the top 150 m of the water column were not accompanied by temperature changes because the upper layer of the ocean is well mixed and isothermal.

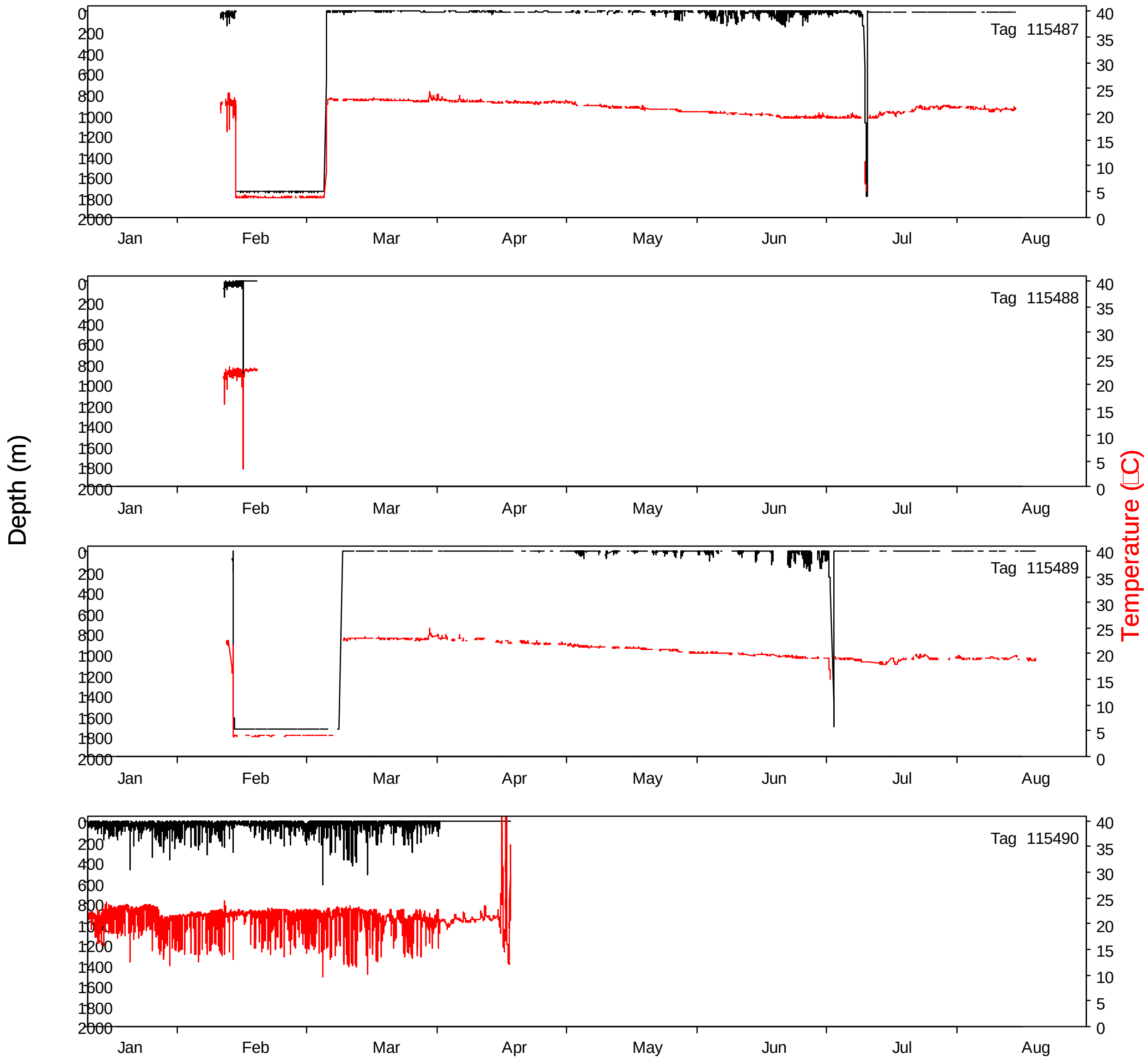

Figure 3: Depth (black) and temperature (red) profiles for four tagged devilrays. Broken lines in the first and third panels indicate incomplete data transmission via satellite.

The best-fit KFSST track of the ray while it was carrying the tag included parameters for latitude bias, solstice error variance (to account for greater error around the equinoxes), and last position not known accurately (because the tag popped up and drifted for 17 days before washing ashore and beginning to transmit). The track suggests the ray did a large loop to the north of New Zealand soon after release, before returning to near North Cape (Figure 2). This is supported by temperature data that show an increase in SST to about 22 ^{o}C soon after tagging as the ray moved offshore into the warm East Auckland Current, and a sharp drop of about 2 ^{o}C when it moved back near the shelf at North Cape on 26 January (Figure 3, Figure 4).

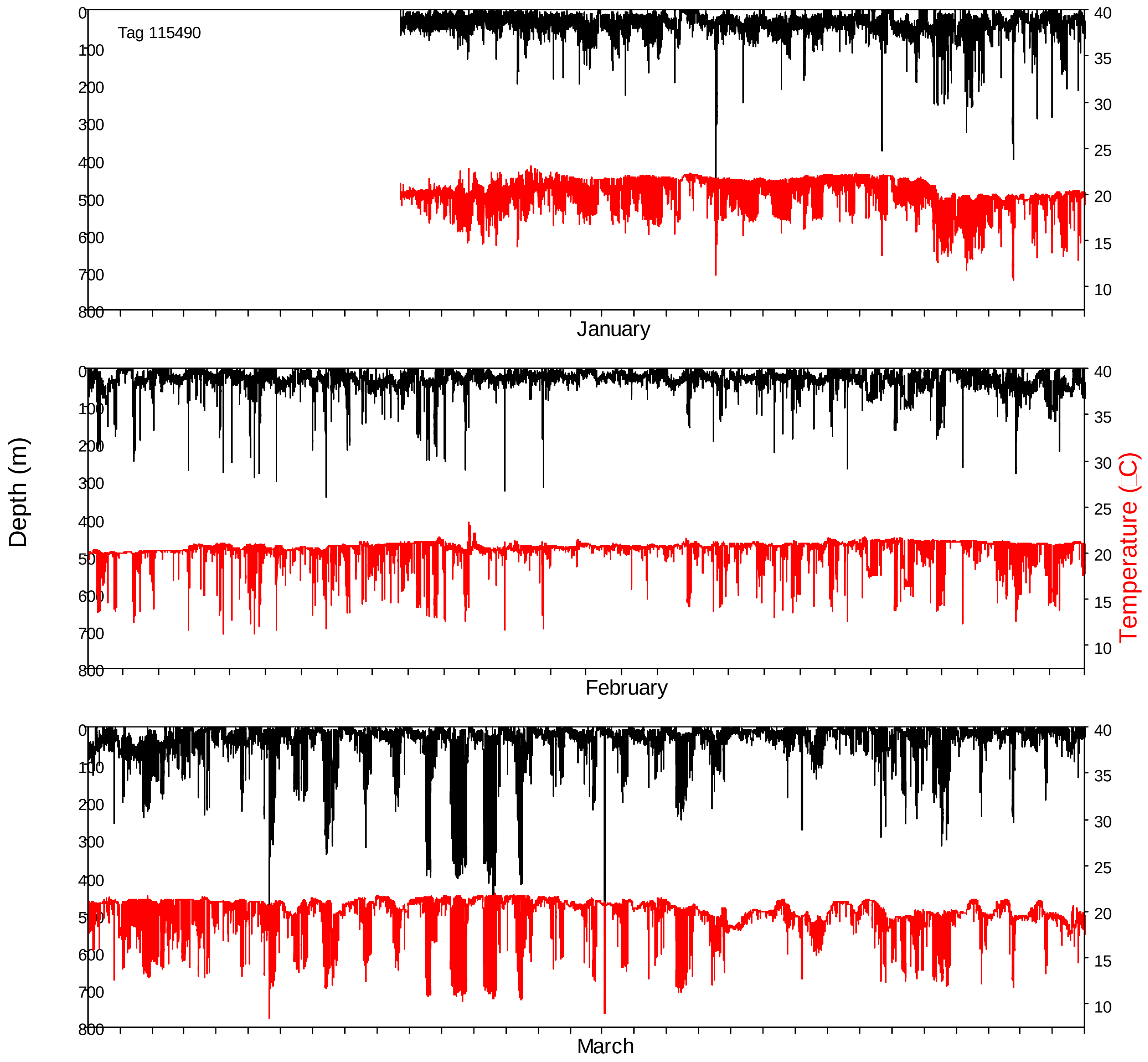

Figure 4: Depth (black) and temperature (red) profiles January-March for one tagged devilray (tag 115490). Each panel represents one month and the X-axis ticks indicate days. The last two days of the track (1-2 April) are not shown.

The ray then spent six weeks off the east Northland coast beyond the edge of the continental shelf, before apparently travelling to the west coast of Northland where the tag popped up. However, popup tag tracks are notoriously error-prone, especially latitudinal estimates made during the equinoxes (March and September). The last one-third of the track occurred during March, so significant latitudinal errors are probable. Inspection of observed and fitted values for tracks fitted using various parameter options indicated a conflict between latitude and SST: when SST was fitted well, latitude was fitted poorly (this was the case for the best-fit track shown in Figure 2), and vice versa. Longitude was well fitted in all models. Thus latitude may have been poorly estimated, particularly during the last one-third of the track. It is plausible that the tag popped up on the west coast and drifted around North Cape and down the east coast before washing ashore. However, it is also possible that the estimated popup latitude is more than one degree too far south, and the popup location was on the east coast of Northland; this scenario may be more plausible given that the tag washed ashore on the east coast. In any event, the track suggests the ray made a loop into offshore waters before returning to near the New Zealand shelf; it apparently stayed within the New Zealand Exclusive Economic Zone for the whole track, i.e. January to March.

Detailed data on depth distribution were available from tag 115490. Over the 82-day period, the ray spent most of its time shallower than 100 m (Figure 5). However, more time was spent in shallow water during the night (2000–0500 hours NZST) than during the day/twilight (0500–2000 hours): the proportions of time spent in 0–25 m, 25–50 m, and greater than 50 m were 60.8%, 28.4% and 10.9% respectively by night, and 43.5%, 34.3% and 22.2% respectively by day (Figure 5)[2]. The median night time depth was 18.5 m and the median day/twilight depth was 28.5 m. The distribution of temperatures experienced was similar by night and day (Figure 6) because most of the water column traversed by the ray was well mixed and isothermal; median temperatures were 20.6 ^{o}C at night and 20.5 ^{o}C by day. However there was a long tail of low temperatures (10–15 ^{o}C) during the day as a result of more deep diving by day than night (Figure 5). There was no diel pattern in the timing of dives deeper than 75 m, but dives deeper than 100 were most common at dusk (1600−1900 NZST), whereas dives deeper than 200 m were nearly all made during the day or twilight, with peaks at dawn (0600–0700) and dusk (1700–1900) (Figure 7). The ray made three dives deeper than 500 m, and reached a maximum depth of 649 m (the deepest parts of these three dives are obscured by the temperature trace in Figure 4).

The ray was very active, making almost continuous vertical movements of at least 30–40 m amplitude (Figure 4). However its vertical behaviour varied considerably through a diel cycle and over the full deployment period. Most days showed movement between the surface and about 40 m, but deeper dives were irregular with some periods having few dives deeper than 200 m (e.g. mid January) and others having many dives deeper than 300 m (e.g. mid March).

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[2] Note that comparisons of behaviour between night and day are only approximate because although day length varies through time, a fixed time period was used to define night and day.

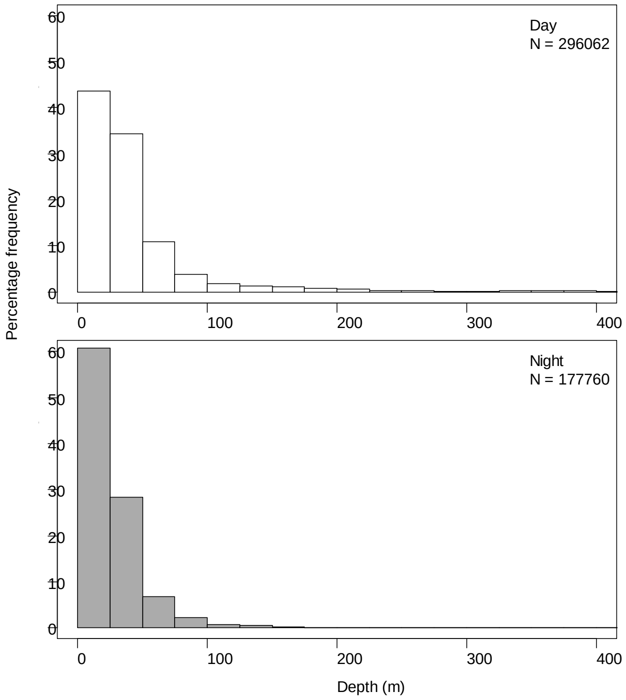

Figure 5: **Depth distribution of a tagged devilray (tag 115490) by day (upper) and night (lower).** N = sample size.

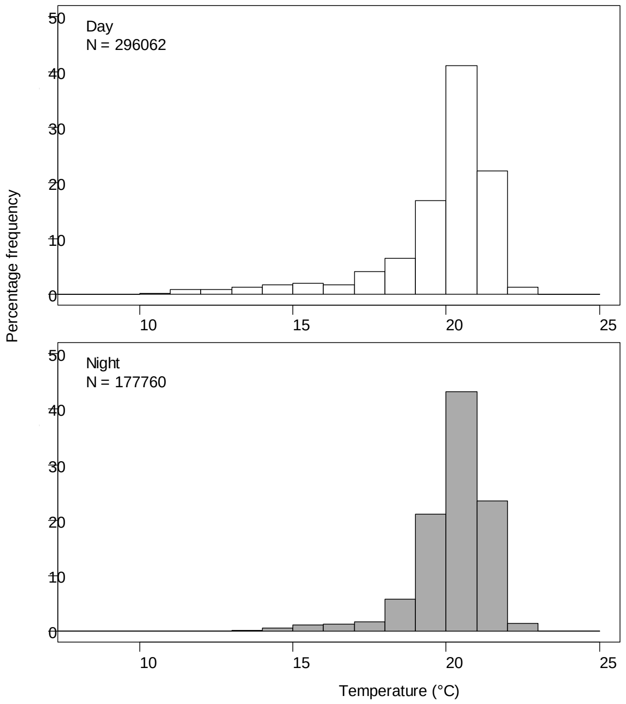

Figure 6: **Temperature distribution of a tagged devilray (tag 115490) by day (upper) and night (lower).** N = sample size.

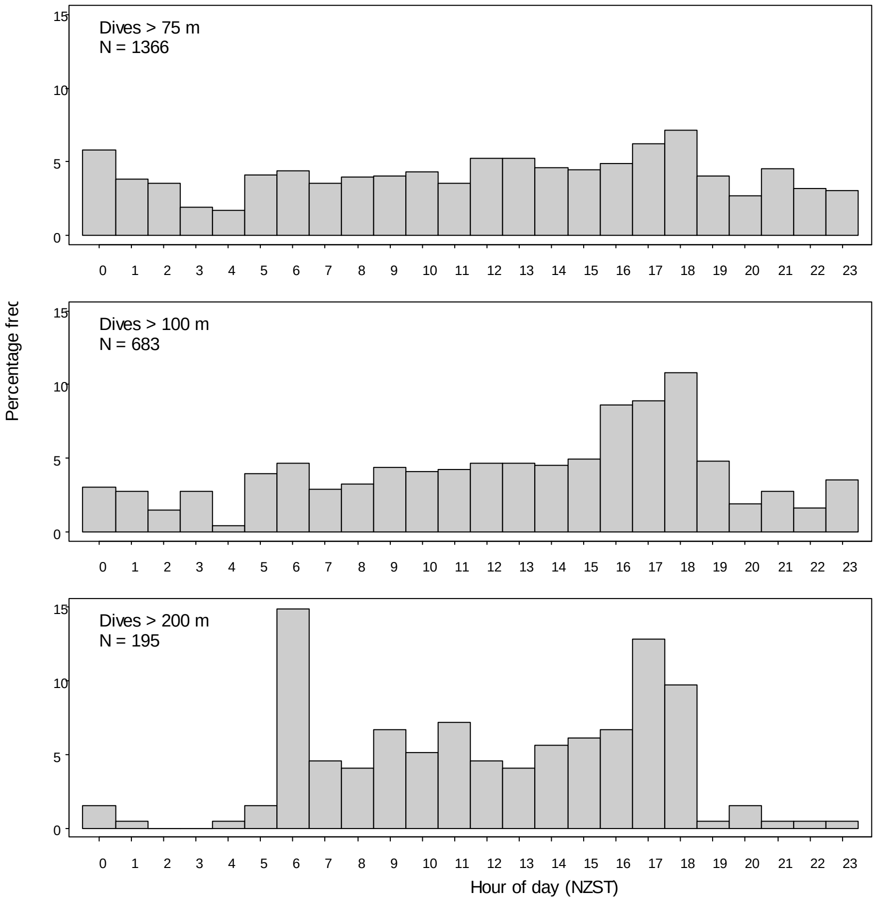

Figure 7: Distribution of start times for dives exceeding 75 m, 100 m and 200 m by a tagged devilray (tag 115490). N = number of dives.

Depth and light traces during six 24-hour periods are shown in Figure 8 to illustrate various vertical behaviour patterns. They include:

A. Continuous, low amplitude, vertical movement with little difference between day and night;

B. Continuous vertical movement with greater amplitude during the day than at night;

C. Highly variable vertical behaviour including periods of negligible movement, at depths of 25−50 m and at the surface, and abrupt changes;

D. Small vertical movements at night, and larger amplitude movements by day including periodic deeper dives to over 200 m;

E. Low amplitude vertical movement by day, with deeper and sometimes lengthy dives from late afternoon to midnight;

F. Negligible vertical movement at night and highly regular deep dives between the upper 50 m and about 350 m during the day.

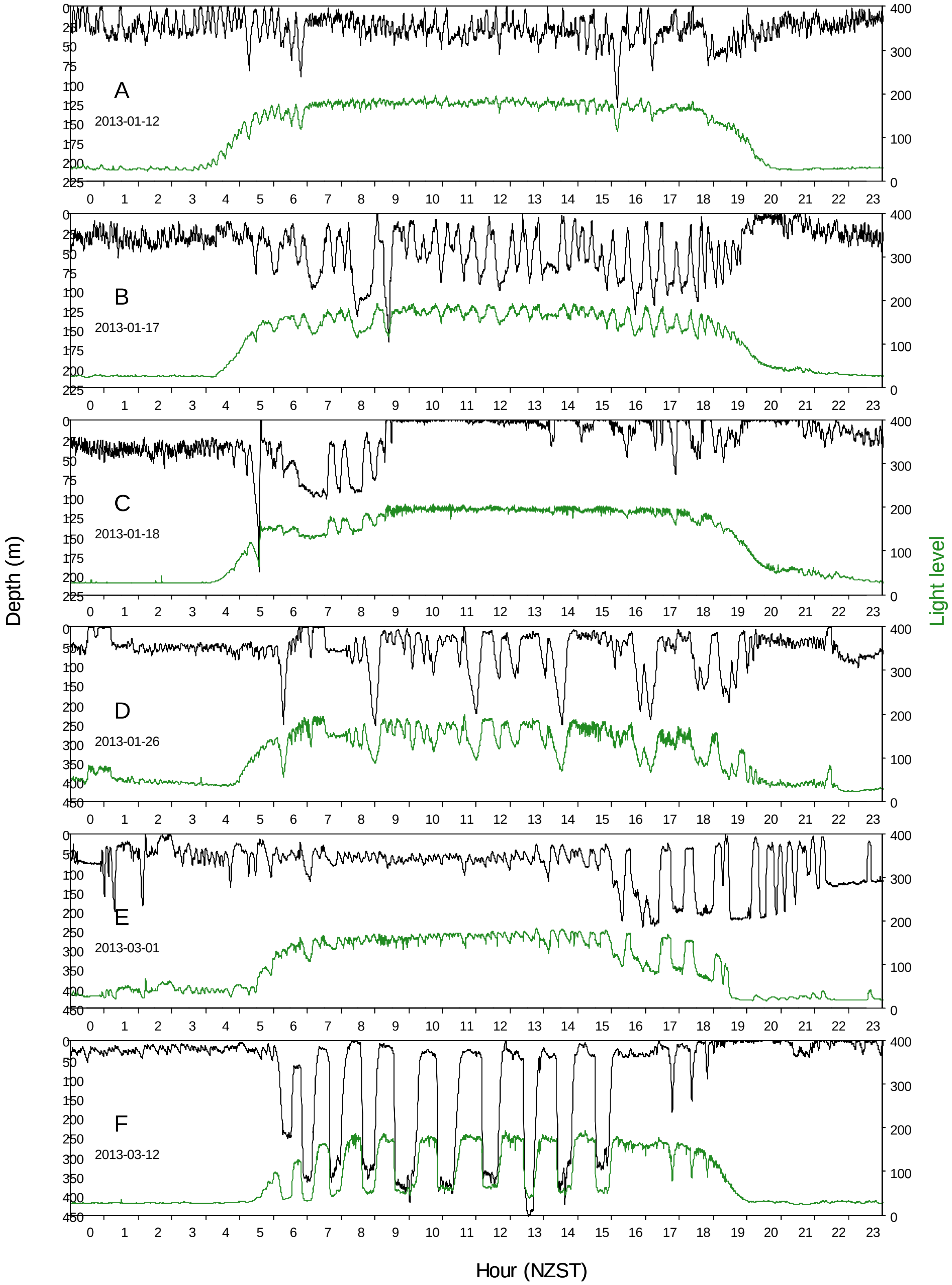

Figure 8: Depth (black) and light (green) profiles for selected days for one tagged devilray (tag 115490). Note the different depth ranges between panels A-C and D-F.

4 Discussion

Distribution and occurrence in New Zealand

Mobula japanica has a worldwide distribution in tropical and subtropical waters, though its occurrence is patchy; for example it has been reported from Queensland and New South Wales in Australia, but not from other Australian states (Couturier et al. 2012). However, field identification difficulties and the offshore occurrence of the species in some regions suggest that some apparent gaps may not be true absences.

Nothing is known about the worldwide population structure of *M. japanica*. In the northeast Pacific, the species does not exceed 2.5 m DW (Notarbartolo-di-Sciara 1987, Croll et al. 2012, Cuevas-Zimbrón et al. 2013), whereas it grows to at least 3.1 m DW in New Zealand (Paulin et al. 1982) and 2.84 m DW in Indonesia (White et al. 2006b). This suggests that there may be separate populations of *M. japanica* in the northeast and southwest Pacific. Polymorphic microsatellite loci have been identified for *M. japanica* (Poortvliet et al. 2011) and a worldwide genetic study is underway on this and other species of *Mobula* (D. Croll, University of California Santa Cruz, pers. comm.) but no results are available yet.

In New Zealand, *Mobula japanica* appears to be restricted to the northern North Island. Devilrays recorded by observers aboard tuna purse seiners were spatially and temporally localised compared with the distribution of the fishery: most records were from the shelf edge off northeast North Island between Great Barrier Island and Cape Brett (35.0–36.5° S) in water depths of 150–350 m, and largely during January–March (Paulin et al. 1982, Francis & Lyon 2012, Jones & Francis 2012). The southernmost record so far reported is at 38.36 ^{o}S (Paulin et al. 1982). New Zealand is at the southernmost limit of the world range of *M. japanica* (Couturier et al. 2012), and devilrays are rarely seen there outside summer, suggesting that they may migrate seasonally into New Zealand waters from subtropical or tropical areas to the north.

The single track obtained for a tagged devilray in this study was not sufficiently long (it did not extend past summer) or accurate to test this hypothesis. However, the track did show that one individual remained close to New Zealand for a period of almost three months. Elsewhere, *M. japanica* has been shown to travel considerable distances, and quite rapidly. In the Sea of Cortez, Mexico, tagged devilrays have been recorded travelling at about 1 knot with bursts up to 4.5 knots, and covering up to 55 km in 24 hours (Freund et al. 2000). Data presented by Croll et al. (2012) for *M. japanica* tagged in the southern Sea of Cortez show straight line movements of more than 1,000 km, but the authors noted that their movements were “not rapid”. New Zealand spinetail devilrays could potentially travel much greater distances than indicated by the single short track obtained here. Longer tag deployments and a larger sample size are necessary to determine the habitat of spinetail devilrays in the New Zealand region.

Behaviour

Mobula japanica is a filter feeder that feeds by straining plankton from the water with their gill rakers. In Mexico, *M. japanica* feeds almost exclusively on the euphausid *Nyctiphanes simplex* (Notarbartolo-di-Sciara 1988, Sampson et al. 2010, Croll et al. 2012). The vertical and horizontal movements of this ray probably reflect its attempts to find and exploit concentrations of prey (Croll et al. 2012). The only previous study to investigate vertical movements in *M. japanica* found similar distribution patterns to those reported here for ray 115490: most time was spent in water shallower than 50 m, with a higher proportion of time in these depths during the night (97%) than during the day (90%) (Croll et al. 2012). SSTs in the Sea of Cortez habitat of *M. japanica* were mostly 20−30 ^{o}C, which is considerably warmer than recorded in New Zealand in this study (mainly 18−24 ^{o}C, modally 20−22 ^{o}C).

In the Sea of Cortez, *N.* simplex, the main prey of *M. japanica*, lives deeper than 50 m during the day, but undergoes a nocturnal vertical migration that brings it to near the surface. This suggests that *M. japanica* feeds mainly at night in surface waters (Croll et al. 2012). Data presented here show that in New Zealand, spinetail devilrays make regular excursions into much deeper water, particularly around dawn and dusk but also at other times of the day, suggesting that at times they also feed on deepwater plankton that has not migrated to the surface. The greatest depth recorded by tag 115490 (649 m) is the deepest yet reported for the species, although a depth of 445 m was reported by Freund et al. (2000). But very little time is typically spent deeper than 200 m by devilrays, and the routine deep diving to 350 m shown in Figure 8F was exceptional. Three tagged *Mobula mobular* from the Mediterranean Sea also showed a preference for waters shallower than 100 m, with occasional deep dives to more than 600 m, particularly during the day (Canese et al. 2011).

Regular up-down movements were frequently observed and varied in amplitude from about 25 m to 75−100 m and rarely 350 m (Figure 8). This behaviour, also reported by Freund et al. (Freund et al. 2000), is often termed oscillatory or ‘yo-yo’ diving, and presumably represents the ray traversing the water column while searching for prey and/or feeding. It is possible that *M. japanica* also undergoes ‘somersault’ feeding (swimming in vertical, backward loops with their mouths open) as reported for *Manta birostris* but this has not been confirmed for *Mobula* rays (Duffy & Abbott 2003).

Survival

With a sample of only four individuals, it is obviously not possible to draw meaningful conclusions about survival rates of spinetail devilrays returned to the sea from the deck of New Zealand purse seine vessels. Nevertheless, the three deaths observed out of four rays released indicate that mortality may be significant. The observer who tagged the rays reported that all swam away vigorously when released, so the poor outcome was surprising. Post-release behaviour is clearly not a good indicator of survival.

Spinetail devilrays tagged in the Sea of Cortez carried popup tags for 14−188 days (the second shortest period was 44 days), indicating extremely good survival. However, the rays were mostly smaller (142−238 cm DW, mean 200 cm DW) than those tagged in the present study and they were not removed from the water for tagging (Croll et al. 2012).

Mobula japanica has been classified on the IUCN Redlist as ‘Near Threatened’ globally, but ‘Vulnerable’ to extinction throughout southeast Asia where catches and demand are increasing (White et al. 2006a). This classification reflects the fact that the species produces only a single, large young per litter, after an unknown gestation period and reproductive cycle duration (White et al. 2006a, Couturier et al. 2012). Size at birth is about 90 cm DW (Paulin et al. 1982, White et al. 2006b, Couturier et al. 2012), though a 56 cm DW neonate (possibly an aborted embryo) has been caught in New Zealand (Stewart 2002). Unvalidated age estimates have only recently been produced for *M. japanica* from Mexico, and they indicate that the rays may grow fairly quickly to 2 m DW by an age of 5 years, and live for at least 14 years (Cuevas-Zimbrón et al. 2013). These preliminary estimates suggest that maturity may be reached (for males at least) by about 5−6 years, but the ageing method still needs to be validated, and applied to southwest Pacific devilrays of both sexes before this can be confirmed.

Until further New Zealand devilrays can be tagged, and a reasonable estimate of mortality of released animals obtained, fishers should be encouraged to release animals from the purse seine net while it is still in the water, rather than after they have been lifted on to the deck, to maximise their chances of survival. The following recommendations made earlier by Jones and Francis (2012) are endorsed here:

- It is recommended that, wherever feasible, manta and devil rays be released prior to hauling and sacking by sinking the corkline and guiding the fish out of the net in some way.
- If this is not possible, removal from the sacked net by targeting and scooping using the brail net should be encouraged and documented. The earlier in the brailing process that this is achieved, the higher the chance of survival.
- If these methods are not feasible, a large mesh cargo net made from soft webbing, should be placed over the hopper before the brail containing the manta / devil ray is emptied. This cargo net can then be used to “sieve” the ray from the tuna catch and lift immediately over the side of the vessel (see Figure 10).
- Leaving manta and devil rays on deck for any length of time should be avoided.

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Appendix A Devilray survival categories.

This scale was developed for use with both sharks and rays, so not all descriptions apply to rays. Based on a scale developed by Braccini et al. (2012)

Index	**Description**	**Survival category**			
		High	**Moderate**	**Low**	**Nil**
Activity & stimuli	Physical activity & response to stimuli	Strong and lively, flopping around on deck, *shark can tightly clench jaws, no stiffness.*	Weaker movement but still lively, response if stimulated or provoked, *shark can clench jaws, no stiffness*	Intermittent movement, physical activity limited to fin ripples or twitches, little response to stimuli, body appears limp but not in rigor mortis, some stiffness	In rigor mortis or dead and limp / lifeless, no physical activity or response to stimuli, *jaws hanging open*
Score					
Skin damage and bruising	Skin damage and surface bruising by physical trauma	No apparent skin damage at all	<5% of skin is damaged showing bruising / redness	5 – 40% of skin is damaged showing bruising / redness	>40% of skin is damaged showing bruising / redness
Score					
Wounds and bleeding	Presence of wounds and any bleeding	No cuts or bleeding observed	1 – 3 small cuts or lacerations / abrasions. Not deep enough to penetrate skin, some bleeding, but not flowing profusely, no exposed or damaged organs	>3 small cuts or 1 severe wound / cut, some bleeding but not flowing profusely, little organ exposure and if exposed, organs are undamaged.	Extensive small cuts or severe wounds, missing body parts, excessive bleeding, blood flowing freely and continuously in large quantities, internal organs exposed and damaged, may be protruding
Score					