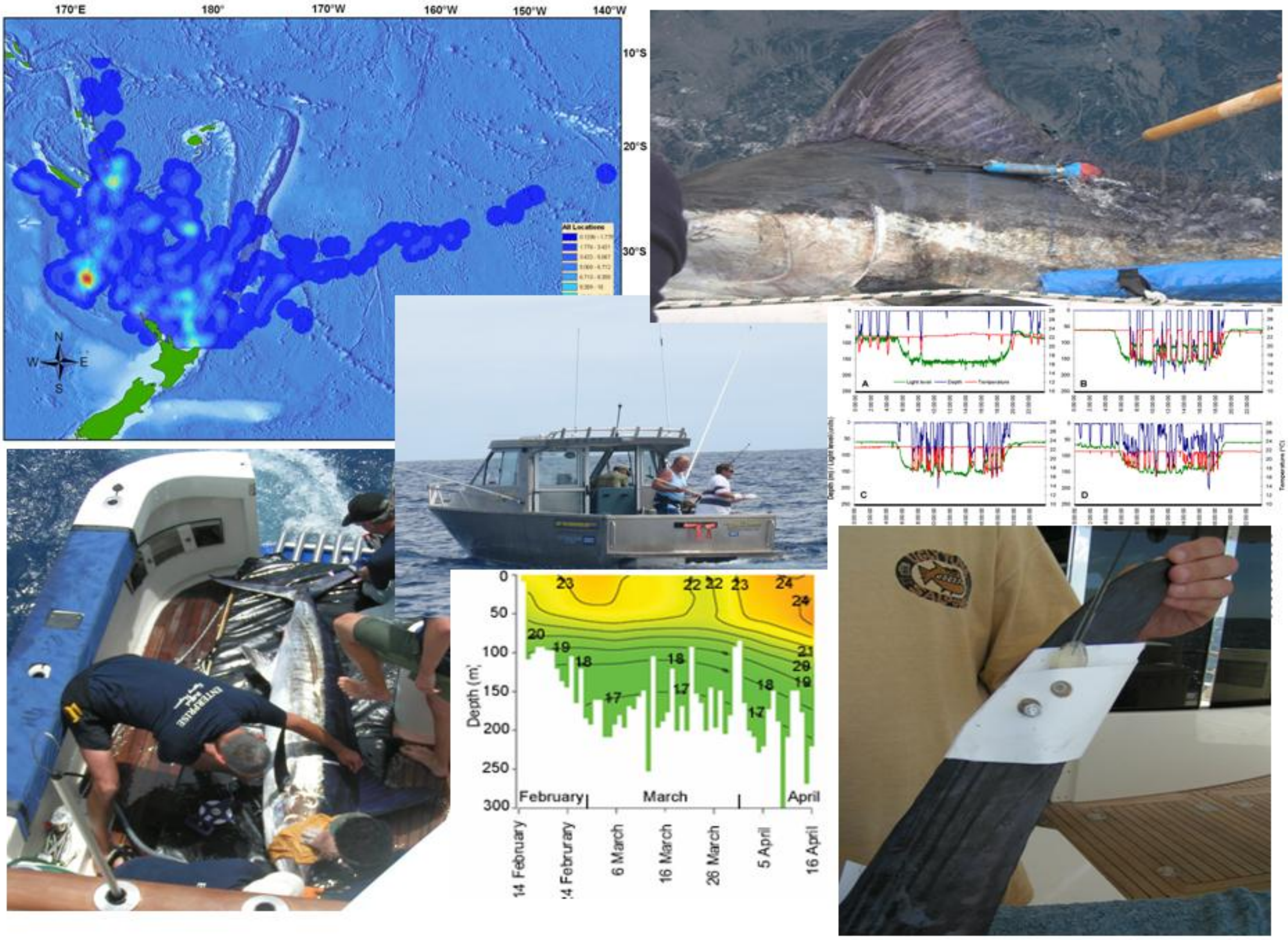
A review of striped marlin movement and habitat selection determined from satellite tag data collected from 2003–2007 in the southwest Pacific Ocean



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EXECUTIVE SUMMARY

The New Zealand Marine Research Foundation's striped marlin satellite tagging research program has spanned four seasons from 2003 to 2007 with numerous achievements along the way. It has proven to be a highly successful collaborative research effort led by Blue Water Marine Research with partners including Massey University, Auckland University, and the Tagging of Pacific Predators program which is operated largely out of Stanford University in the USA. Recreational fishing vessels from New Zealand have been the platforms for all capture and tagging operations, including cooperative efforts where recreational fishers transferring their fish to the tagging vessel, significantly increasing the efficiency of tagging efforts.

In total, 32 striped marlin have been satellite tagged across all seasons, providing an excellent multi-season electronic tagging dataset for the species in the southwest Pacific Ocean. Twenty one of those marlin were tagged at various coastal locations around New Zealand during each year, and 11 were tagged over two trips to the Wanganella Banks in 2006. Across all study years, tagging occurred during five different months (January-May), but they showed a strong tendency to move in a northerly direction from their tagging locations regardless of month or location. Abundance of satellite tagged striped marlin around New Zealand was highest in February and March, with their dispersal rates increasing in April. Some were in the subtropics (roughly 20°S latitude) around New Caledonia, Vanuatu, and Fiji as early as April, and found in New Zealand no later than mid-May. Capturing behaviour of striped marlin around New Zealand's coastal areas proved to be difficult as striped marlin showed a strong tendency to leave their tagging locations immediately upon release. Some returned to their tagging area several weeks later, but most did not return to the area in the same season.

INTRODUCTION

Striped marlin are one of the most important gamefishing species in New Zealand. The reputation for large striped marlin as both fun to catch and good to eat has embedded the species in the traditions of Kiwi sport fishing, as well as being an attractive lure for anglers from overseas. The striped marlin fisheries of New Zealand are generally healthy and strong, and the New Zealand Marine Research Foundation's satellite tagging program has brought New Zealand into a new age of understanding these fish. Since 2003, 32 striped marlin have been satellite tagged through the Foundation's program with substantial support from numerous sources in New Zealand and abroad.

Striped marlin are highly migratory and only a subpopulation of adults reside in New Zealand waters for the austral summer and autumn months. The health of New Zealand's striped marlin fisheries is enmeshed with the health of their populations throughout the Southwest Pacific Ocean. The management of highly migratory species (including billfishes, tunas, and sharks) is by necessity an international effort requiring many nations to agree to management measures in international forums such as the Western and Central Pacific Fisheries Commission.

The pilot project of 2003 provided our first detailed insights into the world of striped marlin as recorded by an electronic tag. It provided the opportunity to fill some of the gaps in our understanding of striped marlin behaviour and environmental preferences. Satellite tag data collected from five tags between February and June that year revealed they spent 80% of their time in the warmer surface mixed layer (usually the top 60 to 80m), or above the thermocline, including more than 70% of their time in the top 5m of water. All the fish survived catch and release but there was an unanticipated trend of striped marlin moving offshore and away from their tagging areas immediately after tag and release. Even fish tagged early in the season did not stay in coastal waters where they were accessible to recreational fishers. All of these observations became important components of subsequent tagging efforts in 2005, 2006 and 2007 and the 2003 study was recently published in an international peer reviewed journal Fisheries Oceanography (Sippel et al. 2007). The 2005 project tagged a further 5 fish and trialed an exciting new method of tracking marlin by attaching transmitters to the upper lobe of their tails. This enabled very high resolution movement data to be gathered and publication of those results is pending now. Tagging in 2006 aimed to build upon the 2005 methods and target tagging efforts over numerous tagging areas and times in an attempt to gather information about their more local behaviours. Fifteen striped marlin were tagged that season in both coastal locations around New Zealand as well as offshore. Tagging in 2007 focused on investigating movement trends observed in 2005 and 2006 of striped marlin from the Bay of Plenty moving along submerged ridges between New Zealand and the Fiji Plateau.

The outcome of these collective efforts is a substantial data set which enables us to investigate many aspects of striped marlin biology and behaviour with respect to their environment. We are beginning to learn how to use these data to enhance the recreational fishing experience through better understanding of the fish themselves as well as to develop ways to ensure their populations remain healthy for future generations.

TAGGING

Tagging methods have been reviewed in detail in previous reports, but a brief account follows. Two different kinds of tags have been deployed. The first is called a PSAT tag (pop-up satellite archival tag) which collects water temperature, diving depth and sunlight intensity data several times each minute. These tags are tethered to a plastic anchor which holds best in the connective tissues underneath the dorsal fin. On a preprogrammed date the tag releases from the fish and transmits summaries of the data to satellites. We get an accurate pop-up location and can calculate approximate daily positions using the light level and temperature data from the tag. These tags are capable of detecting the mortality of the fish and transmitting their data before their pre-programmed date if needed. The second type of tag used is called a SPOT (Smart Position or Temperature) tag which is attached to the upper lobe of the marlin's tail. This tag transmits high quality location (and water temperature) data when the fish's tail is out of the water. No one had attached these tags to a fish tail before so the technique of SPOT attachment was developed and refined from 2005 to 2007.

All fish were caught on lures using a rod and reel. Only fish in good condition were selected for tagging. In 2003 all marlin were tagged around the North Cape and Three Kings areas. In 2005 four marlin were tagged in the Bay of Plenty and one off of Tutukaka. In 2006 11 of 15 marlin were tagged at the Wanganella Banks over 2 trips (January and March/April), and 4 others were tagged around the North Island. All the 6 fish tagged in 2007 were caught in February during the National Contest out from Waihau Bay. The five marlin tagged in 2005 and the six marlin tagged in 2007 were captured by recreational fishers on their own boats then transferred to the tagging vessel. The process works by unclipping the trace from the rod on the capture boat and clipping it onto a line from a rod and reel on the tagging boat. The boats can then move apart and the fish wound in on the tagging boat. The tagging boats line can be thrown between boats by attaching a tennis ball to the end. Table 1 indicates which were tagging boats and which were capture boats (where applicable). The process improves tagging efficiency significantly for the tagging team.

RESULTS

From 32 striped marlin tagged across all years, 1582 days of marlin tracking data were obtained from PSAT and SPOT tags (Figure 2). Figure 1 shows the tracks of all marlin in each year. Figure 2 represents locations of all tagged fish, but filtered for only one location per fish each day. Filtering was necessary for analysis because SPOT tags often provide multiple daily locations. Position information is not available for every day.

Filtered location data were then used to calculate estimates of location density by month in order to identify hot spots and concentrations of position information. Figures 3–10 represent density estimates by month, with their environmental preferences (depth and temperature preferences) below the density maps. The legend in the right corner of the map provides a colour coded key indicating which colours correspond to the number of locations per 1 degree of latitude and longitude. If the key says 4–4.5 next to a shade of red, that means 4–4.5 locations per degree of square longitude/latitude. Below the environmental preferences graphs are tables indicating the proportion of time spent in each data range, broken down by day and night. In the upper right corner of the time at depth graphs is the number of tagged animals represented in the kernel density map and environmental preference data.

Following monthly summaries of data some specific trends of interest are addressed with graphs and plots illustrating the trend and a brief discussion of what the trends mean.

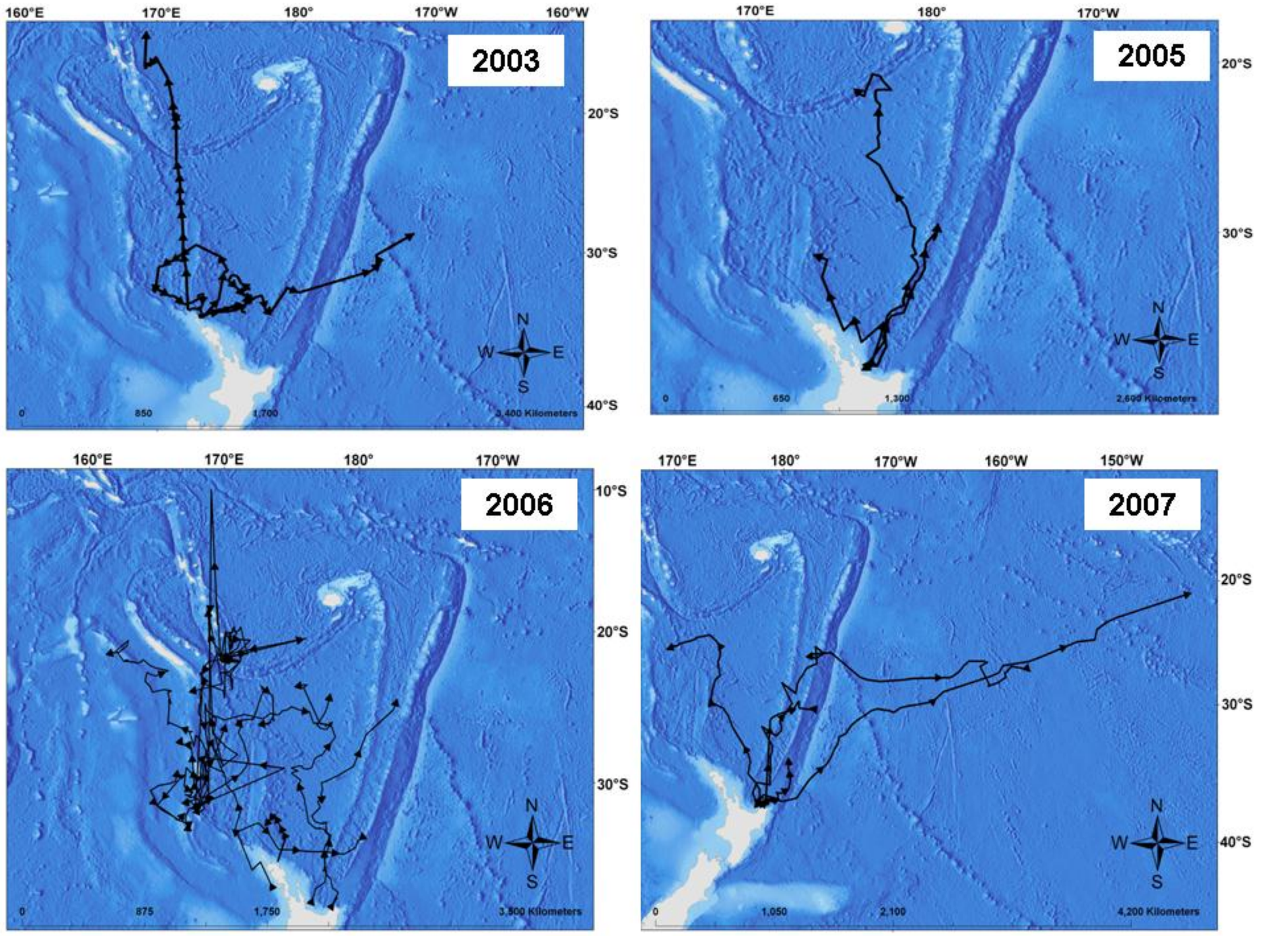


Figure 1. Individual tracks for each marlin tagged during 2003–2007, Eleven fish were tagged at Wanganella Banks in 2006

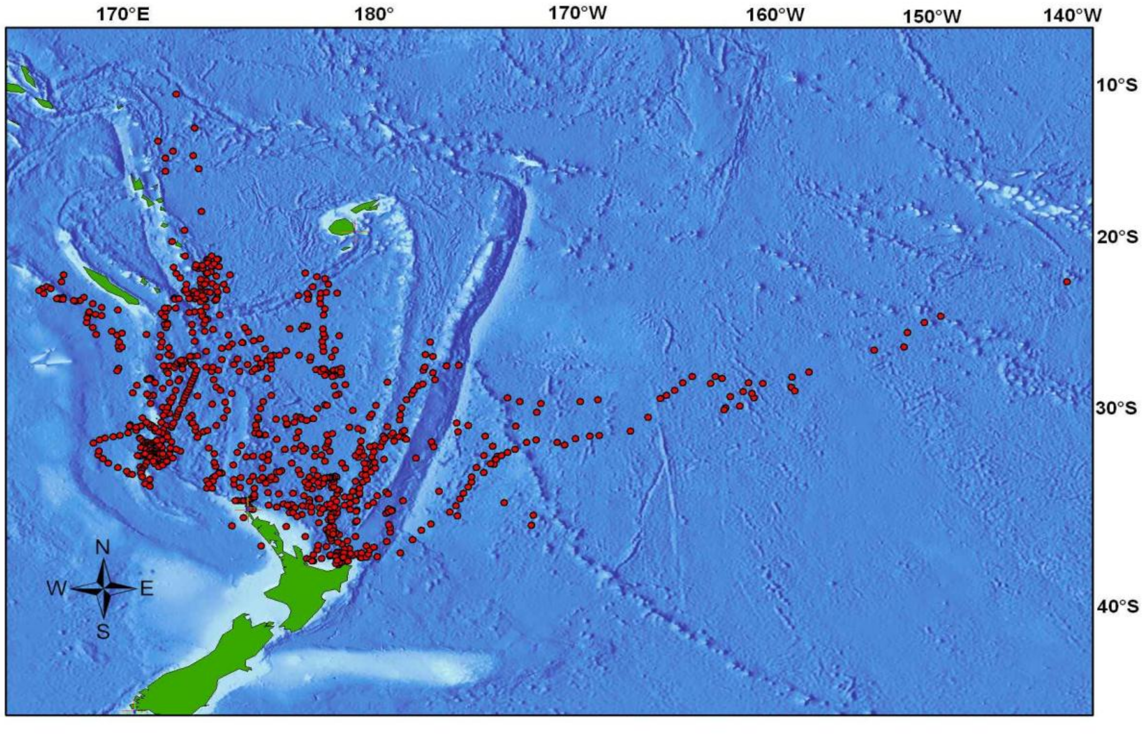
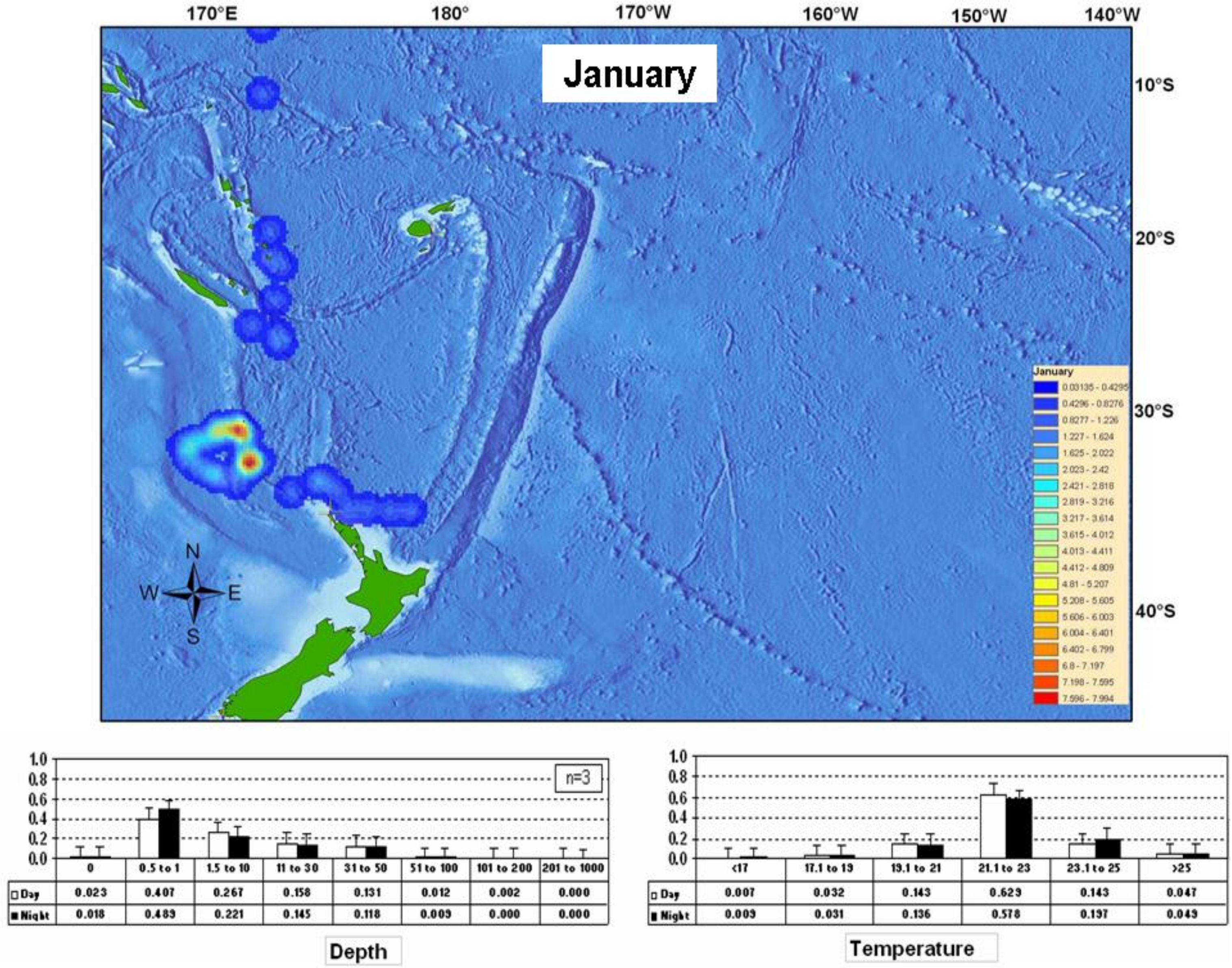


Figure 2. Daily positions from satellite data for all striped marlin tagged from 2003–2007. Note, sometimes there are several days where no position information is received from a fish.

Year	ID	Tagging Date	Tagging Lat	Tagging Long	Tagging Temp	Est Wt	Track End Date	Track End Lat	Track End Long	Days At Liberty	Straight Line Distance (km)	Total Distance (km)	Avg Velocity (km/day)	Capture Vessel	Tagging Vessel	Comments
2003	STM03-1	12/02/03	33.888	172.234	21.1	70	06/03/03	33.642	173.235	22	100	230	10	Learae	Learae	
2003	STM03-2	15/02/03	34.2	172.941	18.8	140	17/03/03	33.633	178.133	30	500	730	24	Learae	Learae	
2003	STM03-3	14/02/03	34.373	173.174	22	80	11/04/03	33.516	173.267	56	100	2130	38	Maverick	Maverick	
2003	STM03-4	16/02/03	34.357	172.999	20.4	120	17/04/03	28.667	-171.417	60	1630	2900	48	Learae	Learae	
2003	STM03-5	10/05/03	33.858	172.208	19.2	100	12/06/03	13.744	169.216	33	2140	2600	79	Prime Time	Prime Time	
2003	STM03-6	23/03/03	34.722	173.619	20.9	85	NA	NA	NA	NA	NA	NA	NA	Lady Jess	Lady Jess	PSAT didn't transmit
2005	STM05-1	21/02/05	-37.2519	176.069	21.6	95	04/03/05	-37.48	178.283	11	106	212	19	Bally Boy	Ubique	
2005	STM05-2	25/02/05	-37.2439	176.103	20.4	85	18/03/05	-31.245	173.185	21	388	406	19	Altair	Ubique	
2005	STM05-3	26/02/05	-37.2953	176.273	23.6	100	19/03/05	-29.506	-179.539	21	512	980	47	Pasadjia	Ubique	
2005	STM05-4	18/03/05	-37.069	176.039	20	70	17/05/05	-21.703	176.134	60	922	6836	114	Attitude	Ubique	
2005	STM05-5	23/03/05	-35.316	174.463	22.1	90	05/04/05	-33.453	173.796	13	117	NA	NA	Nobel Princess	Rona G	Killed by shark
2006	STM06-1	10/01/06	-32.635	167.563	22.5	74	21/03/06	-31.897	167.068	71	51	701	10	Ultimate Lady	Ultimate Lady	
2006	STM06-2	11/01/06	-31.6833	167.833	22.4	80	25/01/06	-31.368	168.824	15	54	3000	201	Ultimate Lady	Ultimate Lady	
2006	STM06-3	12/01/06	-31.7067	167.835	23.2	81	26/04/06	-33.014	167.582	105	79	758	7	Ultimate Lady	Ultimate Lady	
2006	STM06-4	13/01/06	-31.7438	167.88	22.6	66	17/05/06	-21.703	176.134	124	747	577	1	Ultimate Lady	Ultimate Lady	PSAT didn't transmit
2006	STM06-5	04/02/06	-36.5133	173.629	21.4	110	02/05/06	-24.105	167.376	87	811	1706	20	Ultimate Lady	Ultimate Lady	
2006	STM06-6	20/02/06	-37.6458	177.813	22.3	66	26/04/06	-24.191	177.85	66	807	1269	19	Ultimate Lady	Ultimate Lady	
2006	STM06-7	01/03/06	-37.3973	176.374	21.9	66	26/05/06	-24.553	182.792	87	838	1028	12	Ultimate Lady	Ultimate Lady	
2006	STM06-8	31/03/06	-31.7063	167.846	22.8	65	28/04/06	-20.163	168.855	28	695	985	35	Ultimate Lady	Ultimate Lady	PSAT didn't transmit
2006	STM06-9	13/02/06	-34.8581	173.757	21.7	81	02/03/06	-32.715	172.98	17	134	158	9	Ultimate Lady	Ultimate Lady	PSAT didn't transmit
2006	STM06-10	31/03/06	-31.7063	167.846	22.8	75	11/08/06	-21.717	161.812	134	681	1934	14	Ultimate Lady	Ultimate Lady	
2006	STM06-11	31/03/06	-31.7068	167.852	22.7	95	07/06/06	-23.757	175.176	68	615	1777	26	Ultimate Lady	Ultimate Lady	Killed by shark
2006	STM06-12	02/04/06	-31.7086	167.833	22.5	80	06/05/06	-26.22	170.12	35	350	737	21	Ultimate Lady	Ultimate Lady	
2006	STM06-13	03/04/06	-31.6667	167.817	22.4	90	02/05/06	-26.276	172.453	29	405	1006	35	Ultimate Lady	Ultimate Lady	
2006	STM06-14	03/04/06	-31.6833	167.85	22.6	80	12/07/06	-21.817	170.404	101	608	2644	26	Ultimate Lady	Ultimate Lady	
2006	STM06-15	04/04/06	-31.6988	167.845	22.5	76	22/04/06	-27.073	166.87	18	282	243	14	Ultimate Lady	Ultimate Lady	PSAT didn't transmit
2007	STM07-1	19/02/07	-37.4851	177.982	20	85	02/06/07	-20.101	225.579	103	2678	3204	31	Silver Lining	Brave Hart	SPOT tag only
2007	STM07-2	19/02/07	-37.4082	178.344	21.3	60	19/04/07	-30.686	182.979	59	464	1746	30	Vitamin Sea	Brave Hart	SPOT tag only
2007	STM07-3	20/02/07	-37.5087	177.847	20.9	75	11/04/07	-25.611	169.269	50	837	1162	23	Sidewinder	Brave Hart	SPOT tag only
2007	STM07-4	20/02/07	-37.5602	177.66	21.2	100	21/05/07	-27.421	-157.412	90	1395	2644	29	Attitude	Brave Hart	
2007	STM07-5	21/02/07	-37.3725	177.754	21.2	80	11/03/07	-34.448	180.7	18	226	323	18	Peacemaker	Brave Hart	SPOT tag only
2007	STM07-6	22/02/07	-37.4866	178.027	20.8	95	25/2/2007	-37.275	178.071	NA	NA	NA	NA	Ocean Cowboy	Brave Hart	Died upon release

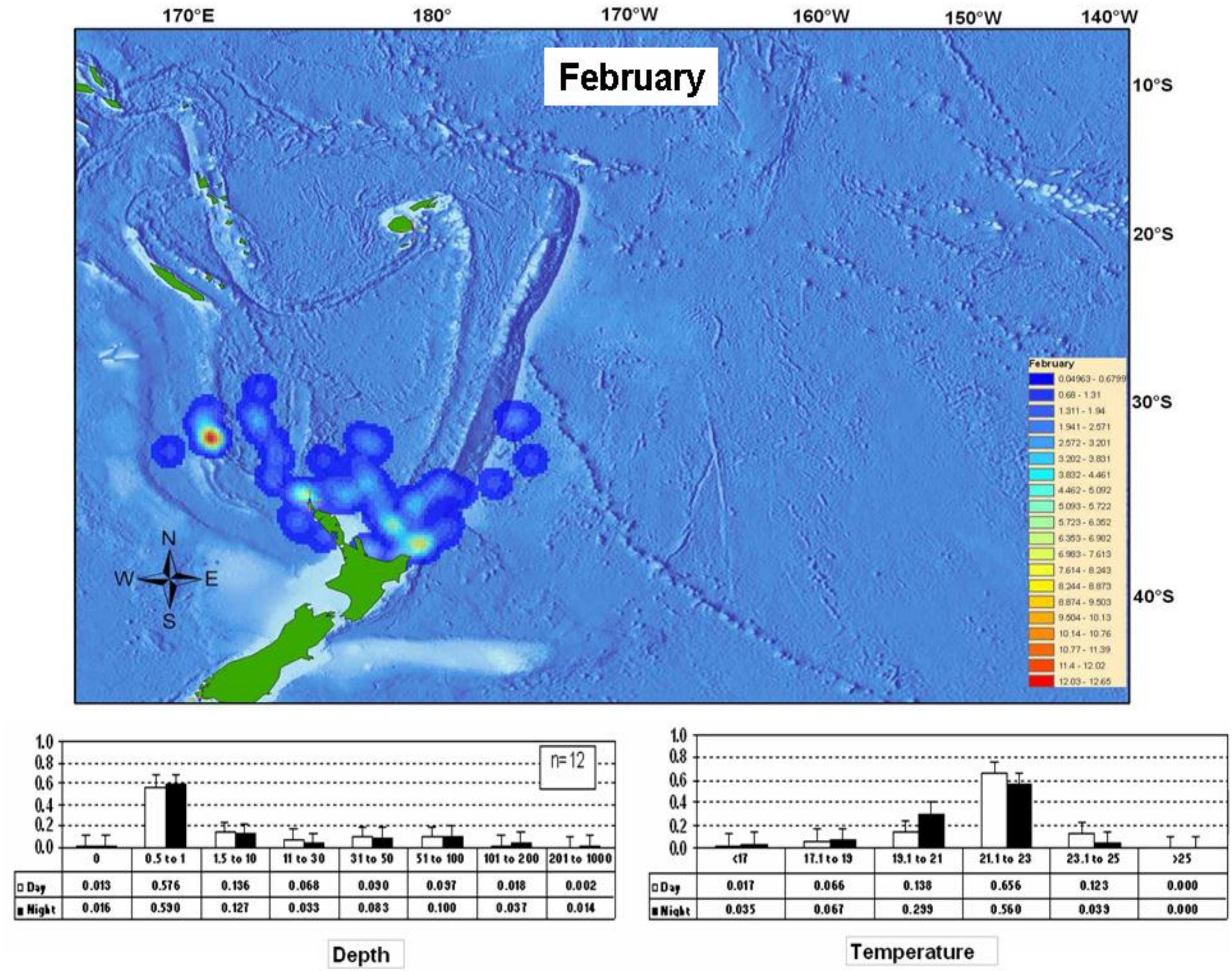


	0	0.5 to 1	1.5 to 10	11 to 30	31 to 50	51 to 100	101 to 200	201 to 1000
□ Day	0.023	0.407	0.267	0.158	0.131	0.012	0.002	0.000
■ Night	0.018	0.489	0.221	0.145	0.118	0.009	0.000	0.000

	<17	17.1 to 19	19.1 to 21	21.1 to 23	23.1 to 25	>25
□ Day	0.007	0.032	0.143	0.629	0.143	0.047
■ Night	0.009	0.031	0.136	0.578	0.197	0.049

Figure 3. Top: Location density estimates for the month of January across all years. Bottom: Time at depth and temperature during January across all years, white bars for day, black bars for night.

All locations during January were collected from tags attached to 3 marlin in 2006 from tagging at the Wanganella Banks. The density map (Fig 3.) shows high densities of locations around the Banks themselves. The circular pattern of density around the banks is from two marlin, which initially moved north, then circled back to within about 100km of their tagging locations several weeks later. One of these fish then moved back north past the eastern edges of New Caledonia and Vanuatu. Another marlin initially moved eastwards from the banks and then southeast past New Zealand and onto the Kermadec Ridge. All these marlin showed a strong affinity for the top 50m of water, which may have been influenced by the shallow depths of the Wanganella Banks themselves (<100m). 40% of their time during the day and 50% during the night was spent within a metre of the surface (peaks on the depth plot bottom left of Figure 3). 60% of their time was spent in 21–23 degree water, with little difference between day and night. Again this reflects shallow depth preferences within the mixed layer.



	0	0.5 to 1	1.5 to 10	11 to 30	31 to 50	51 to 100	101 to 200	201 to 1000
□ Day	0.013	0.576	0.136	0.068	0.090	0.097	0.018	0.002
■ Night	0.016	0.590	0.127	0.033	0.083	0.100	0.037	0.014

	<17	17.1 to 19	19.1 to 21	21.1 to 23	23.1 to 25	>25
□ Day	0.017	0.066	0.138	0.656	0.123	0.000
■ Night	0.035	0.067	0.299	0.560	0.039	0.000

Figure 4. Top: Location density estimates for the month of February across all years. Bottom: Time at depth and temperature during February across all years, white bars for day, black bars for night.

Across all years 16 marlin were tagged in the month of February. Of those 16 tagged, good data was transmitted from 12 PSAT tags for inclusion in analyses of environmental preferences. Their latitudinal range spread from 30–38°S and 170°E–175°W, including concentrations around the Wanganella Banks, the northern tip of New Zealand, and off East Cape. An expanded cluster of density is apparent around the Bay of Plenty (Fig. 4) and this begins to show clustering around the southern end of the Colville-Lau Ridge which extends from the Bay of Plenty up to the Fiji Plateau (west of the Kermadec Ridge). The affinity of striped marlin for the Colville-Lau Ridge began to emerge in 2005 and was subsequently observed again in 2006 and 2007. Although 60% of their time was spent in the top 1m of the water column, descents to the range of 51–100m were also apparent. With many of the fish spending time in deeper waters than January, dives to deeper depths were more regular. However, temperature preferences were similar to January, with 60% of their time spent in 21–23 degree water. This suggests that depth of the mixed layer often fell into the 51–100m depth range during February.

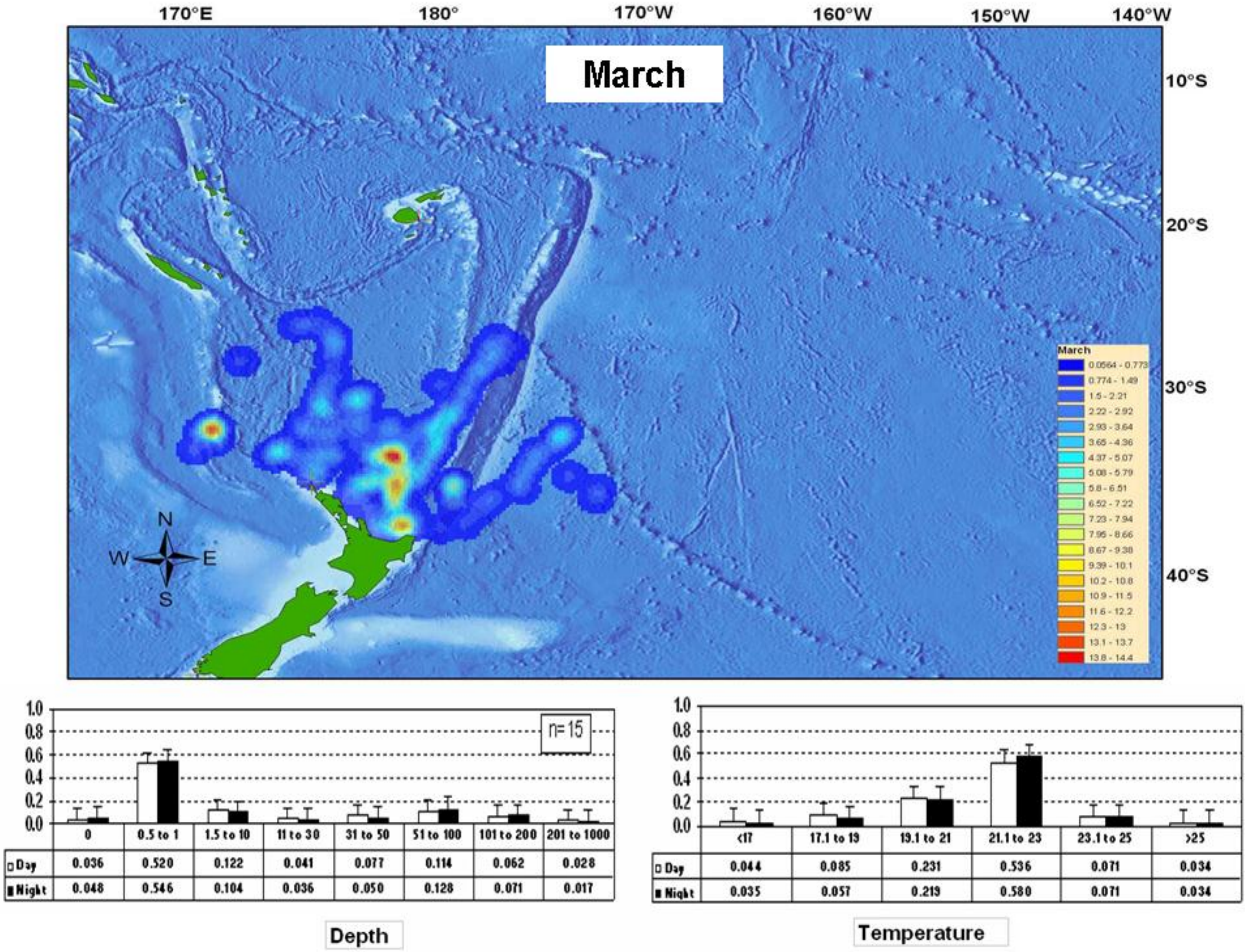


Figure 5. Top: Location density estimates for the month of March across all years. Bottom: Time at depth and temperature during March across all years, white bars for day, black bars for night.

Across all study years, more data was collected in the month of March than any other month. Clusters of high location densities persisted around the Wanganella Banks, as well as north from the Bay of Plenty. The Wanganella clustering (Fig 5.) was associated with tagging late in March 2006. Hotspots around Bay of Plenty and northwards were associated with striped marlin moving along the Colville-Lau Ridge and to the west of the ridge, with 2 fish in 2006 and 1 in 2007 diverting at very similar locations from the Ridge into deeper waters where seamounts are located, but no apparent pattern of subsurface structure (such as the Colville-Lau Ridge) is apparent. The northern and eastern extent of observed movements expanded to 27°S and 170°W. Descents to 100–200m, and even more than 200m increased in frequency. These increased proportions of time at depth occurred during the same period that several marlin frequented the area west of the Colville Ridge, where they spent up to 10 days before moving on. This is very likely associated with foraging. Foraging tends to be associated with repeated diving in pursuit of prey, which would explain the deeper diving frequencies. However, the depth of the mixed layer tends to increase while moving into the subtropics and so deeper dives would often remain in relatively warm mixed layer temperatures. This probably helps to explain why temperature preferences remained consistent with previous months.

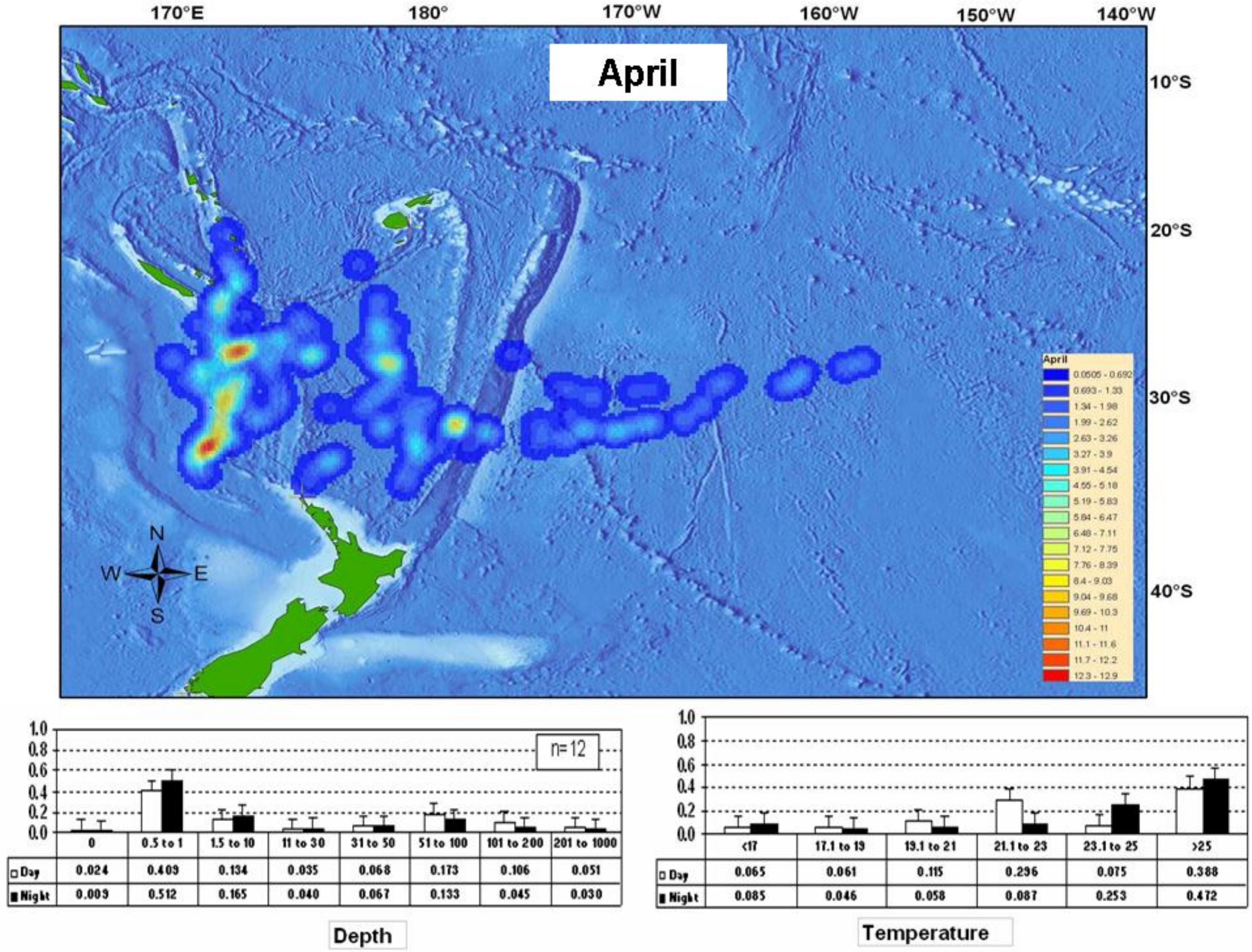
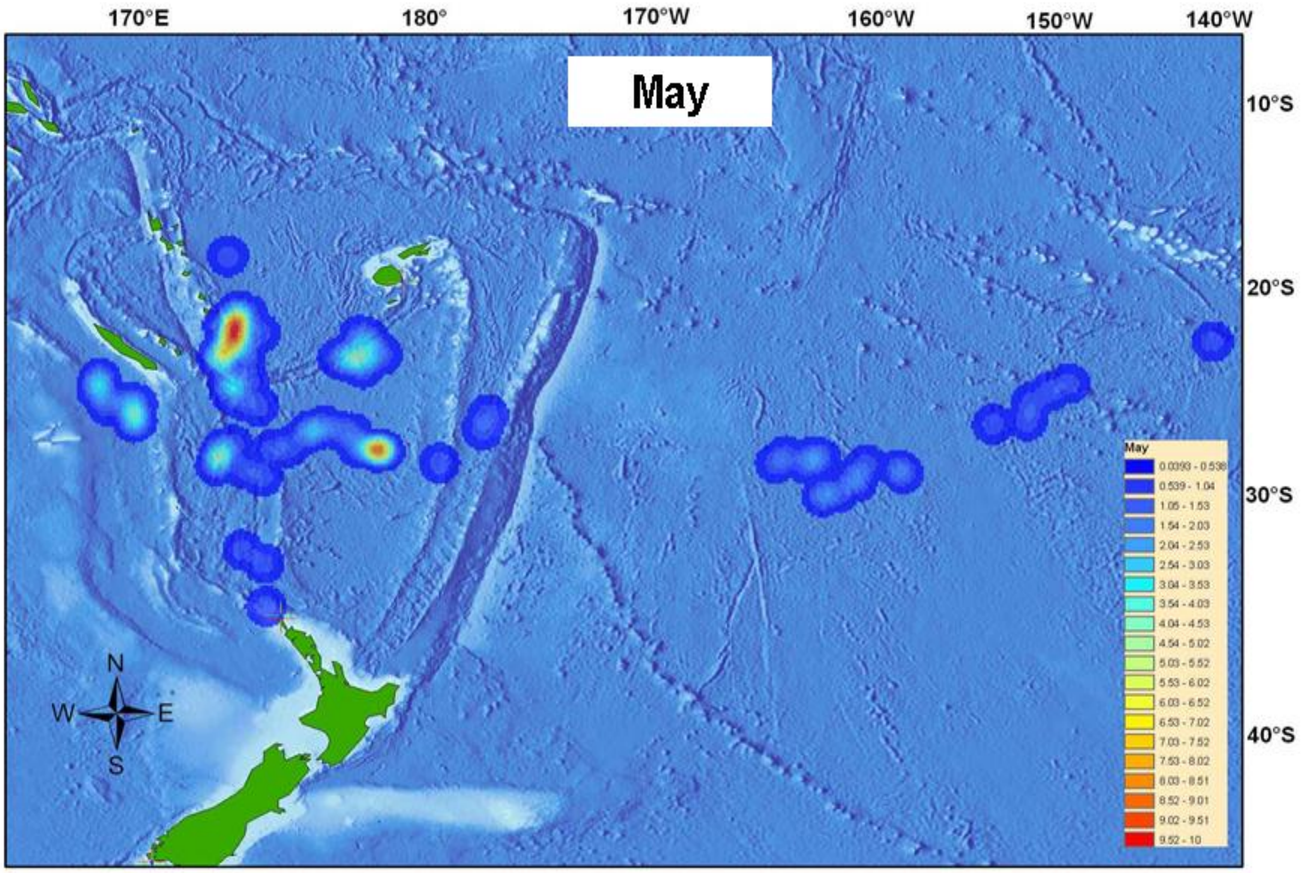


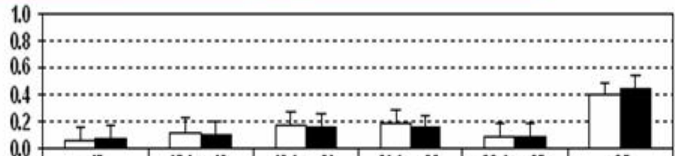
Figure 6. Top: Location density estimates for the month of April across all years. Bottom: Time at depth and temperature during April across all years, white bars for day, black bars for night.

Data from 12 fish during April show a clear geographic shift northwards, but with more association to the Wanganella Bank and Norfolk Ridge (Fig 6.). However, half of these fish were tagged at the Wanganellas in late March and early April. Following tagging they moved immediately northwards, and did not return to the banks as some marlin did in January. This suggests that the natural trend of northerly movement around this time of year precluded returning to their tagging regions. The northerly movements of Wanganella fish towards eastern New Caledonia and Vanuatu was common amongst all fish tagged at this time. High location densities are also apparent around 28°S south of Fiji and over the Kermadec Ridge around 30°S. Two marlin from 2007 left the Waihau Bay tagging area approximately 1 week apart, but followed similar trajectories along the Colville-Lau and Kermadec Ridges before turning east and eventually following similar paths between 160–170°W. These two fish followed trajectories along the 25°C sea surface temperature (SST) contour line, which could suggest a thermal preference for these two fish. However, the general temperature preference trend shifted in the month with the bulk of time during April spent in waters warmer than 25°C. Again with the northerly shift towards subtropical waters where the mixed layer depth tends to be deeper the fish spent more time at depth with around 20% of their time spent in water deeper than 50m, especially during the day.



	0	0.5 to 1	1.5 to 10	11 to 30	31 to 50	51 to 100	101 to 200	201 to 1000
□ Day	0.007	0.498	0.156	0.030	0.037	0.129	0.113	0.030
■ Night	0.004	0.595	0.151	0.053	0.067	0.081	0.042	0.008

Depth

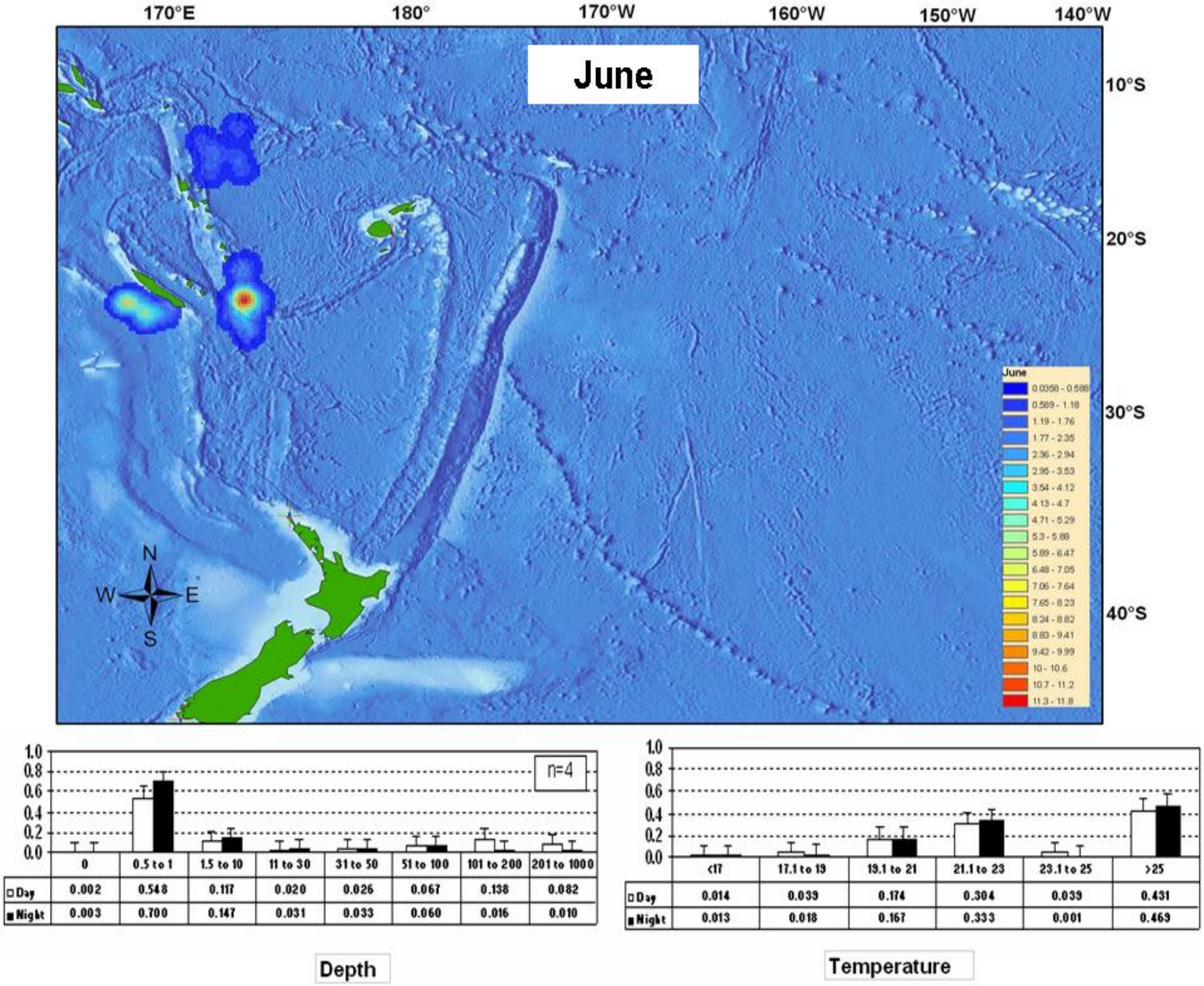


	<17	17.1 to 19	19.1 to 21	21.1 to 23	23.1 to 25	>25
□ Day	0.054	0.123	0.166	0.184	0.086	0.387
■ Night	0.071	0.103	0.152	0.147	0.088	0.440

Temperature

Figure 7. Top: Location density estimates for the month of May across all years. Bottom: Time at depth and temperature during May across all years, white bars for day, black bars for night.

Data from 9 marlin show that by May almost all locations were north of 30°S latitude, with the exception of a one marlin tagged at the Three Kings Islands in mid-May 2003. A cluster of locations was located to the east and south of New Caledonia and Vanuatu and south of Fiji (Fig 7). One marlin in 2007 moved out to 140°W, or the eastern extreme of any marlin tracked by this project. Depth and temperature preferences were very similar to those observed in April though more time was spent right at the surface, 50% during the day and 60 % at night.

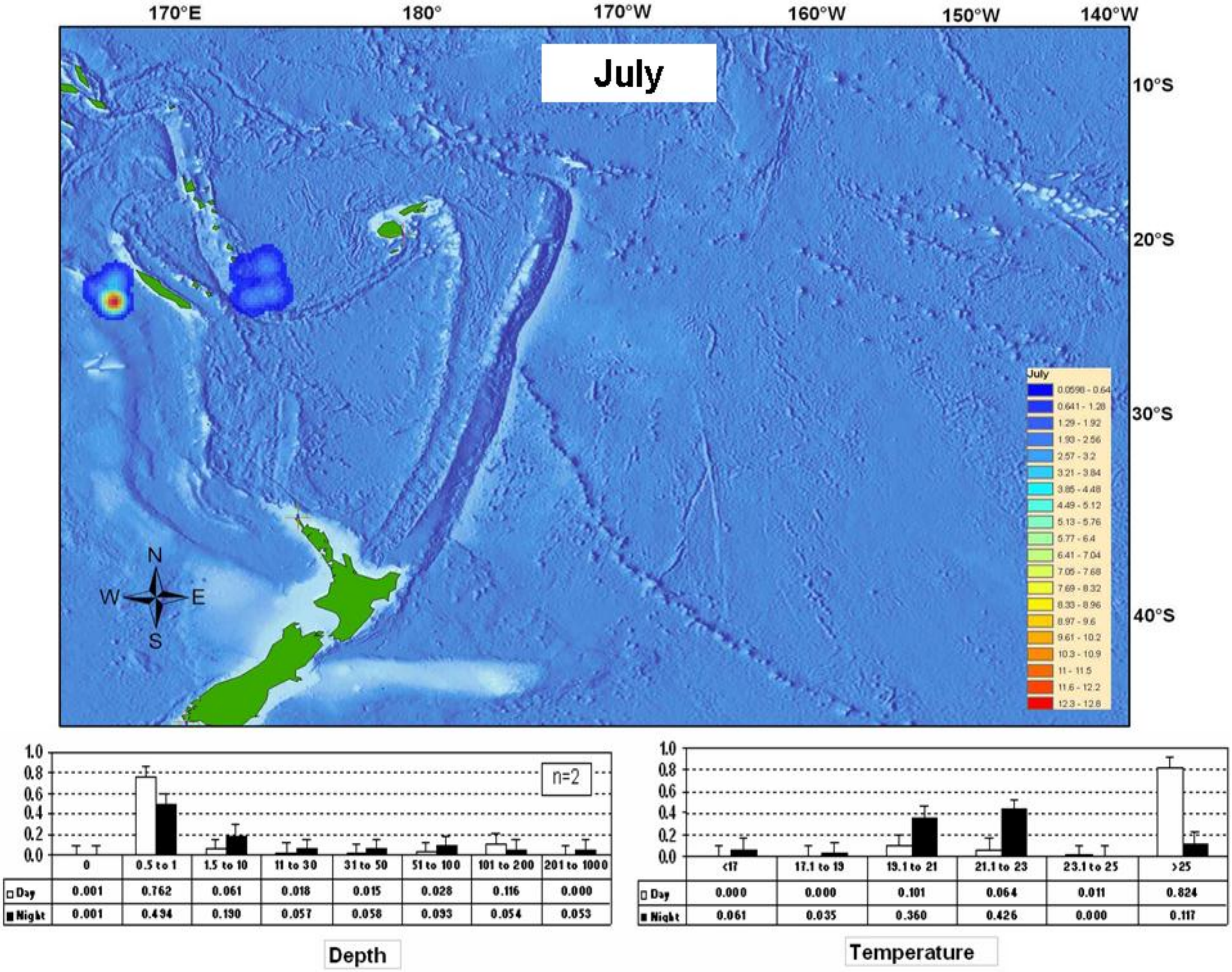


	0	0.5 to 1	1.5 to 10	11 to 30	31 to 50	51 to 100	101 to 200	201 to 1000
□ Day	0.002	0.548	0.117	0.020	0.026	0.067	0.138	0.082
■ Night	0.003	0.700	0.147	0.031	0.033	0.060	0.016	0.010

	<17	17.1 to 19	19.1 to 21	21.1 to 23	23.1 to 25	>25
□ Day	0.014	0.039	0.174	0.304	0.039	0.431
■ Night	0.013	0.018	0.167	0.333	0.001	0.469

Figure 8. Top: Location density estimates for the month of June across all years. Bottom: Time at depth and temperature during June across all years, white bars for day, black bars for night.

By June data from the remaining 4 fish show no locations were near New Zealand. All were to the east and west of New Caledonia and northeast of Vanuatu (Fig 8.). Proportions of time at depths greater than100m became more significant (about 20% during the day) again indicating a deep mixed layer where they were probably foraging. Mixed layer temperatures were warmer than 25°C and again deeper than around New Zealand. Water temperatures down to 100m and deeper remained warmer than 19°C.



	0	0.5 to 1	1.5 to 10	11 to 30	31 to 50	51 to 100	101 to 200	201 to 1000
□ Day	0.001	0.762	0.061	0.018	0.015	0.028	0.116	0.000
■ Night	0.001	0.494	0.190	0.057	0.058	0.093	0.054	0.053

	<17	17.1 to 19	19.1 to 21	21.1 to 23	23.1 to 25	>25
□ Day	0.000	0.000	0.101	0.064	0.011	0.824
■ Night	0.061	0.035	0.360	0.426	0.000	0.117

Figure 9. Top: Location density estimates for the month of July across all years. Bottom: Time at depth and temperature during July across all years, white bars for day, black bars for night.

The geographic distribution of the two remaining fish during July looks similar to June, with a high density of locations on the west side of New Caledonia, and lower density on the east side (Fig 9.). Interestingly, a shift in depth distribution becomes apparent, with nearly 15% of their time at night spent deeper than 50m. This depth preference shift is apparent in proportions of time at temperature as well, with significantly more time spent between 19.1 and 23°C at night than day. Reasons for increased night time preferences for deeper/cooler waters are uncertain. A hypothesis to explain this could be night time foraging for prey such as squid which ascend towards the surface at night.

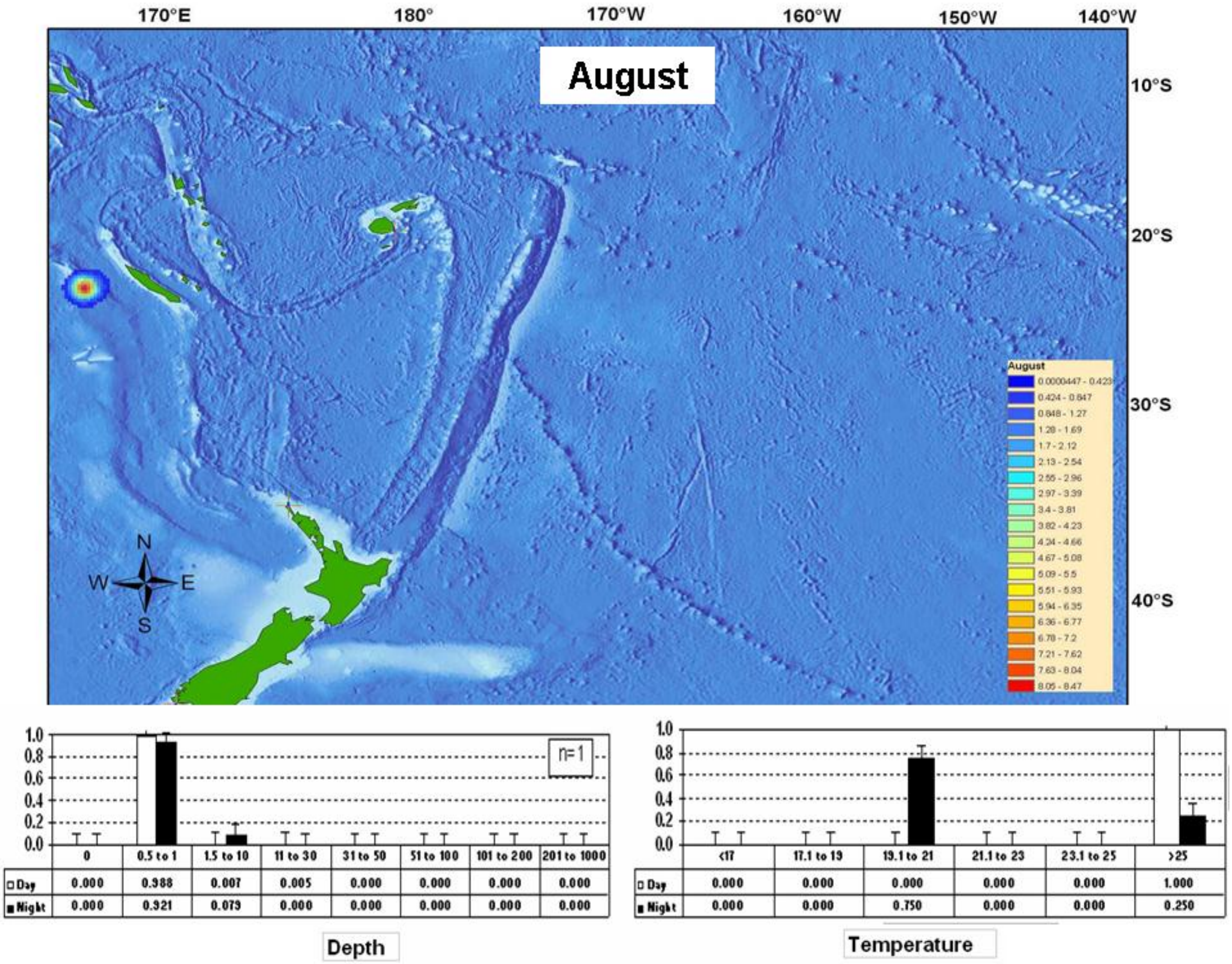


Figure 10. Top: Location density estimates for the month of August across all years. Bottom: Time at depth and temperature during August across all years, white bars for day, black bars for night.

One marlin carried a PSAT tag into early August, and all of its locations were clustered off western New Caledonia (Fig 10.). This tag only recorded a few days of data during August. Interesting differences in depth and temperature preferences emerged, with almost all of its time spent at the surface, but night time forays to only 10m resulted in night time temperature decreases to 19.1 to 21°C degrees. It is difficult to draw confident conclusions with these sparse data, but it could suggest that it has spent time where the mixed layer was particularly shallow. However, more data would be required to attempt to understand what could have been happening here.

SPECIFIC TRENDS

Returning to capture locations

At least 4 marlin (1 in 2003, and 3 in 2006) moved away from their tagging locations but returned several weeks later to the vicinity of their capture, or were at least moving toward the general area of capture and tagging when their track stopped (Figure 11). Interestingly, all four were tagged in January or February, and no similar return journeys were observed from marlin tagged in later months. Regardless of when or where marlin were tagged, they consistently moved away from their tagging locations. The intention of tagging marlin at Wanganella Banks in early January was to try and track a southward migration, hopefully to New Zealand. That the few who returned to their tagging locations only did this when tagged early in the season might suggest that post-release striped marlin behavior is perturbed by the capture and/or tagging so they move away from that area. The return journeys suggest early in the season they are likely to still encounter favourable conditions in the area they were tagged. But as the season progresses, it might not be worth their effort to return as conditions may be less favorable. This is why it was so difficult to gather information about their behavior around New Zealand's coastal areas and within the range of recreational fisheries.

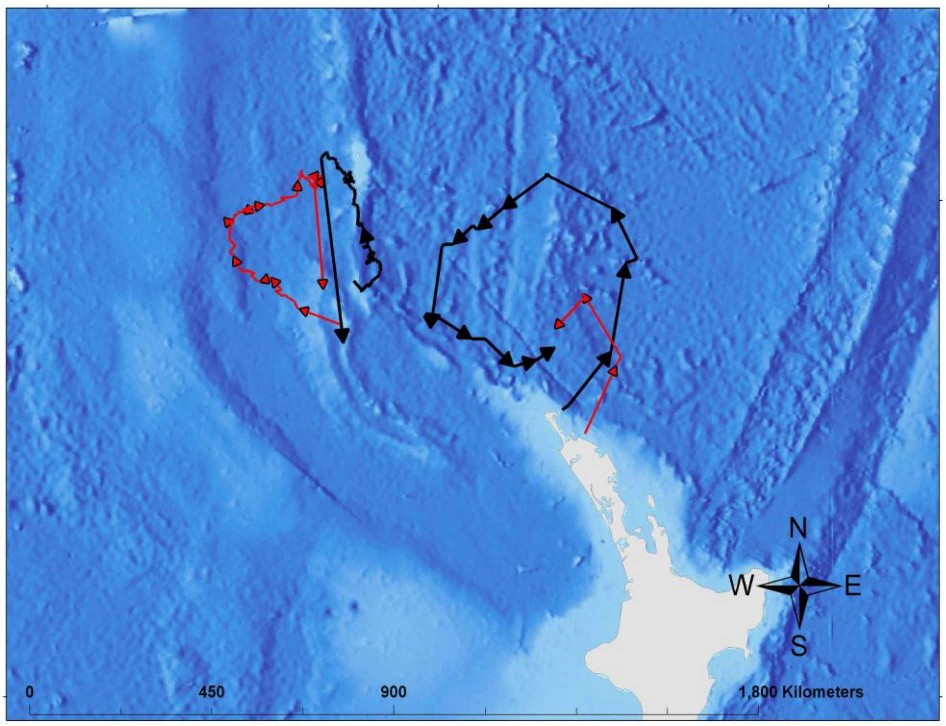


Figure 11. Four marlin that left their tagging locations upon release, but returned several weeks later.

Coastal movements

One striped marlin carrying a SPOT tag remained in the vicinity of its tagging location for three weeks after tagging at Waihau Bay in February 2007 (Figure 12). After release it moved east before backtracking west and circling around about 40 km northwest of Cape Runaway for about 2 weeks. It then moved slowly eastward before turning to the northeast and moving more quickly in a deliberate and directed track. This marlin was tagged with a SPOT tag only, so unfortunately depth and temperature preference information from a PSAT associated with the coastal movements is not available. However, the deliberate nature of its eventual offshore movements could suggest some environmental or biological cue may trigger when striped marlin leave New Zealand waters. However, this normal cue might be overridden or prematurely triggered by the capture and/or tagging process which would explain the immediate movements away from tagging locations that have been observed. Testing this hypothesis is difficult, but we still have some PSAT and SPOT tags left for 2008. Specially designed tag deployment strategies will be used in an attempt to address the uncertainty surrounding possible capture induced movements away from tagging locations.

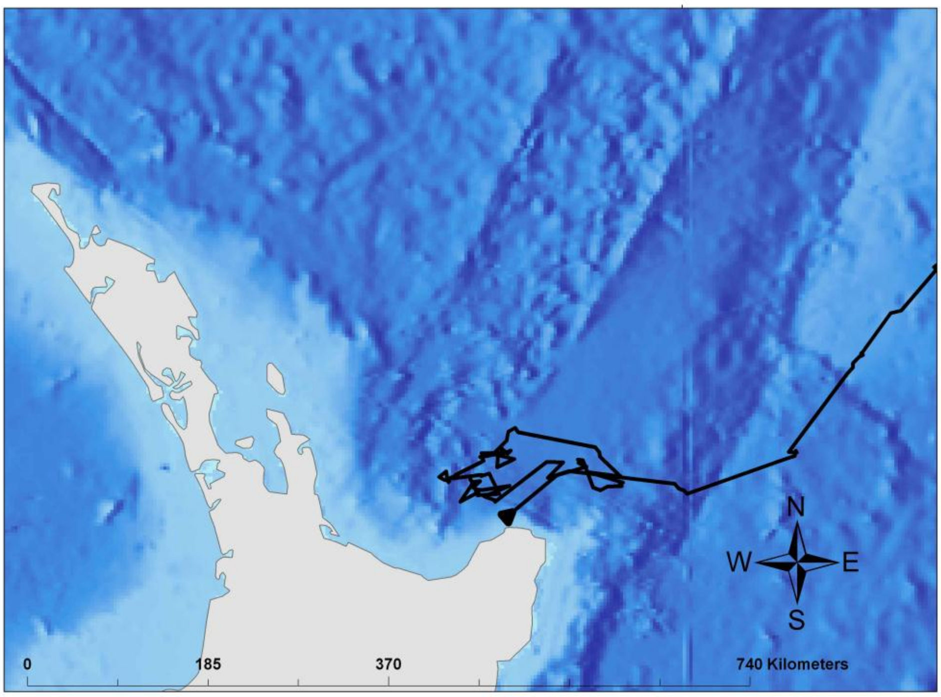


Figure 12. One striped marlin which spent notable time near its tagging location in 2007 for several weeks before leaving.

PSAT tag recovered reveals data recorded every minute for 2 months

One of the tags deployed on 14 February 2003 at North Cape popped off a striped marlin on 17 April 2003, 300 nautical miles east of Raoul Island. Over the ensuing 30 months the tag drifted westward and eventually washed up on the coast south of Noosa Beach, Queensland, Australia. The return of this tag provided the most detailed picture of striped marlin movements through the water column we've seen yet. Six 24 hour periods in the life of this marlin revealed by this tag are shown in Figure 13. The blue lines represent depth, green represents sunlight intensity, and red represents water temperature. Changes in light phases (day/night/twilight) can be traced along the green line. Following day/night/twilight trends we can clearly see bounce diving patterns repeatedly during the day, but fewer dives at night. When looking closely we can see the maximum depth of dives begins to increase around dawn and decreases around dusk (see panels D, E, and F). This is consistent with foraging behaviour (ie. feeding) and particularly day time feeding, and reinforces the notion that striped marlin (and marlin in general) rely heavily on vision while foraging. However, the increased night time diving behaviours observed in July/August (Figs 9 & 10.) in the tropics might suggest predation squid and other prey at night too; but this is only speculation.

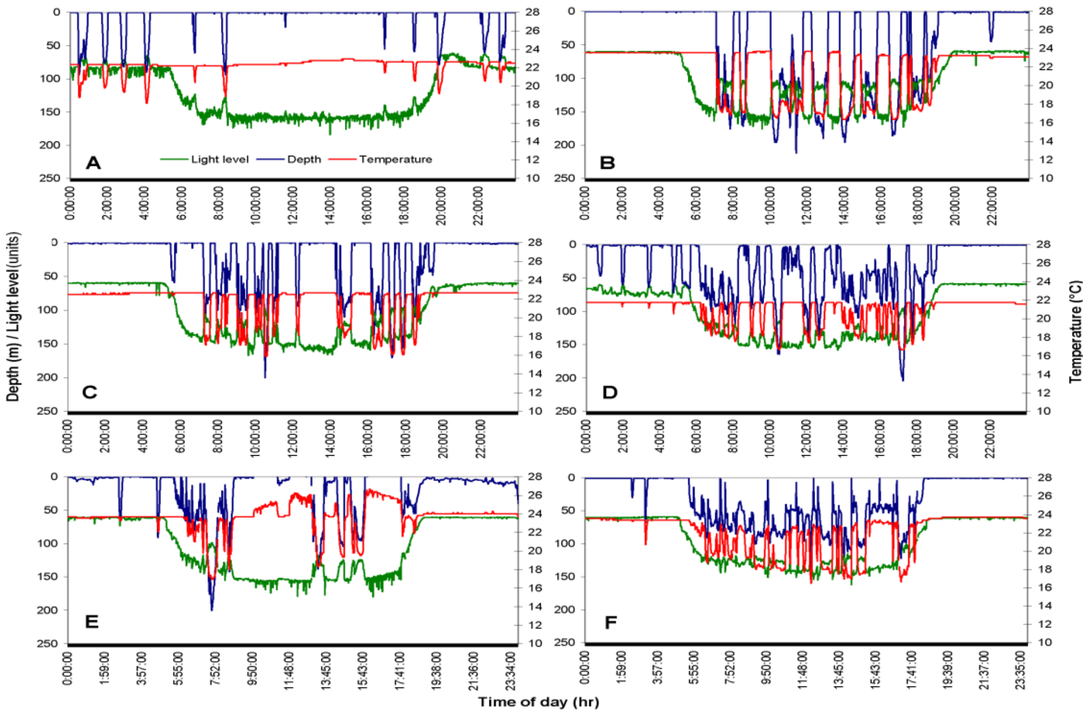


Figure 13. Six days of archival data recorded every 60 seconds by the PAT tag attached to STM03-4. Each plot starts at midnight; hours are along the bottom scale. The depth and light scale is on the left. Depth is the blue line; the scale is 0 to 250 m. Light level is the green line which reads about 60 at night and about 160 during the day on this scale. Temperature is the red line with the scale from 10 to 28 degrees on the right. The dates for each plot are: A. 19 February. B. 6 March. C. 10 March. D. 25 March. E. 4 April. F. 8 April.

Recovered tag reveals behaviour immediately after release

The recovered tag revealed details of the fishers behaviour immediately following release. The fish remained in the top 10 meters of water for the first 90 minutes. Then it dived to 87 metres where the water was 16 degrees, and returned to the surface. The dive lasted 25 minutes and was followed by 50 minutes in the top 10 meters. There were four more bounce dives that day; each between 20 and 30 minutes in duration. At dusk the fish dived and spent the next 7 hours between 40 and 85 meters. The water temperature varied quite often over a 3 degree range as the fish was regularly traversing through the thermocline. The daytime behaviour of this fish following release is simlar to other days later in the track. However, spending so much time away from the surface at night is very unusual, and was not observed again during the track. For the next few days the fish spent a lot of time at the surface during the day, with bounce dives at night and often at dawn and dusk. The archival record revealed diving behaviour was notably different in the first 10 days after the fish was tagged and released. Note the difference of patterns in panel A (5 days after tag and release) versus all other panels (more than 20 days after release). Again these patterns could be consistent with a period "disturbed" behaviour following catch and release.

Shark predation on tagged striped marlin

At least two striped marlin were killed and eaten by sharks while carrying PSAT tags. We believe this because the sharks swallowed the tags while the marlin showed normal diving behaviour. The first instance occurred in 2005 after tagging the marlin off Tutukaka. It was eaten14 hours after being released. Evidence is strong that the shark which ate the marlin was from the Lamnid family of sharks. These include mako, porbeagle and white sharks. A unique characteristic of this family of sharks is that they are warm blooded, maintaining body temperatures which are warmer than the water they are in. This provides a unique signature to our tag records as this marlin was tagged in 22°C water, but temperature records in Figure 14 below show temperatures at 27°C degrees. Furthermore, it shows dives to 600m depth while temperature remained around 27°C. And finally, there were no sunlight measurements from this tag. All of this is consistent with the tag (and its marlin victim) sitting inside the stomach of a lamnid shark for 10 days before the tag was ejected and still managed to transmit its data!

A similar incident happened in 2006, with a tag from a marlin released at the Wanganella Banks. It recorded 6 weeks of normal data as the fish moved up to New Caledonia, before it too was eaten by a Lamnid shark and transmitted data very similar to these. Although it is disappointing to have our marlin succumb to predators, these data are fascinating and seem to shed light on the harsh world they live in. Of particular interest was the 2006 marlin surviving capture and release but falling prey 6 weeks later in New Caledonia. This suggests that lamnid sharks are quite capable of attacking striped marlin which appear to be healthy (or at least healthy enough to swim from the Wanganella Banks to New Caledonia).

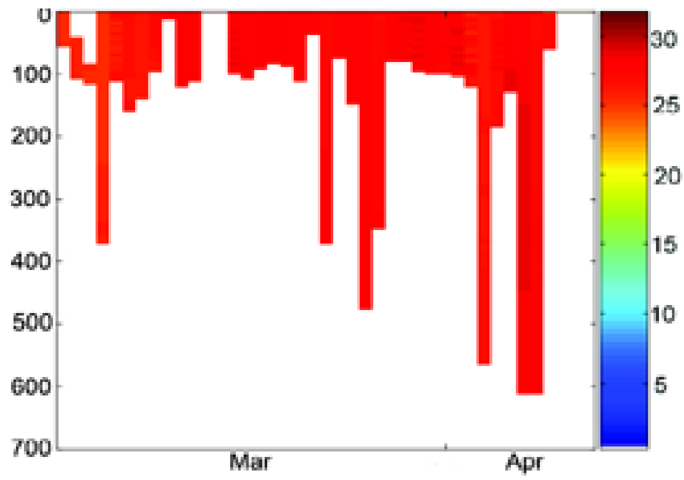


Figure 14. Profile of depth and temperature of a marlin eaten by a lamnid shark hours after release in 2005 off Tutukaka. Depth is on the y-axis (ranging from 0 to 700m) and temperature is represented by the colour bar in degrees Celsius (ranging from 0 to 30) and time (by month) is on the bottom x-axis.

DISCUSSION

A treasure trove of data has been gathered through these projects. Some of the data gathered meet the original objectives of these projects, and some data gathered point to unanticipated directions which open up new questions. An important outcome of these projects is the survivorship rates demonstrated for recreationally caught striped marlin. Only one marlin died upon release as a direct result of the capture and tagging process. This was an apparently healthy fish in 2007. Another tag in 2003 did not transmit any data, so we can not say what happened to it. But the predation by sharks on tagged marlin might hint at the fate of this non-reporting tag. It is both impressive and surprising that two satellite tags survived the initial shark attack, continued to operate in the shark's stomach, before being spat out and successfully transmitting their data. One would expect some tags to be destroyed in a shark attack, and this is one of many possible explanations for non-reporting tags.

Biofouling a problem for long term tags
Four PSAT tags deployed in 2006 did not report but the SPOT tag tracks showed the fish survived. We wanted to get longer term information from marlin over the spring spawning period and on into the next summer. The deployment periods were set to 11 months but these tags failed to transmit. The likely cause for this is marine growth, which seems far worse on tags when the fish spend much of their time near the surface. We use anti-fouling paint on all the striped marlin tags but this must wear off.

Striped marlin survive tag and release
In the end, we can confirm 31 out of 32 marlin survived the capture and tagging process and swam away with PSAT and/or SPOT tags which functioned for between 11 and 131 days, although two fish were later eaten by sharks. Satellite tagging studies in California (Domeier et al. 2003) found that 63% of striped marlin hooked in the gut or gills died within two days of release. However, the use of circle hooks significantly reduced deep hooking and dramatically improved the chances of survival. Acoustic tracking surveys in the early 1990's in California and Hawaii (Holts and Bedford 1990; Brill et al. 1993) also confirmed high rates of post-release survivorship, particularly when the fish were handled properly.

Cash rewards for recovered PSAT tags
As has been emphasized throughout these projects there is very high value in recovering these electronic tags. The benefits of tag recovery have been discussed and demonstrated here. Cash rewards continue to be available for the return of tags recovered from this program. Other international research programs are willing to pay for the return of their tags as well. The best thing to do with recovered tags is use the contact information (phone numbers and email addresses) printed on the tags themselves. By doing this, the owners of the tags will be notified and will be able to arrange rewards for the recovered tags.

Tail tags deliver the most detailed movement information so far
The development of a method to attach SPOT tags to marlin has been extremely valuable. Initial deployments in 2005 provided proof of concept and lasted a maximum of 21 days before either the tags or their attachments failed. Improvements to the attachment and tag design enabled SPOT tracks of up to 43 days to be gathered in 2006. Further refinements to the tag attachment method and reinforcements to the tags themselves in 2007 resulted in SPOT tracks as long as 102 days, showing movements past Tahiti and Pitcairn Islands. There is significant scientific value in such high quality data. They can be used to better understand the dynamics influencing the speed, direction and timing of striped marlin movements. These data can also be used to assess the

accuracy of various computer models. Importantly, the SPOT data will be used to assess the accuracy of computer models that estimate the location of fish carrying PSAT tags using day length and SST data. Because most species are not suitable for SPOT tags, and only PSAT tags can be used to study their movements, the calibration of the computer models that estimate locations from PSAT tags are very important.

Striped marlin are good navigators

It was often observed that striped marlin movements were quite deliberate, usually in an initial northward direction from their release location. Effectively two modes of movement were observed. The first are deliberate and directed movements which often lasted for weeks at a time and could be associated with migration. The second are what we refer to as passive movements in which they seem to hang around a particular area for a time. However, seldom were directionless meandering movements observed. These observations suggest striped marlin are navigators that are able to use environmental cues to guide the direction and speed of their movements. The passive movements probably reflect opportunistic foraging opportunities they encounter along the way.

These SPOT tag locations are not as accurate as GPS, but this may not be far away

Additional information from SPOT tags is being used to understand aspects of marlin behaviour. It is common for several days to pass after a marlin is released before the first transmissions are received by satellites. This suggests that striped marlin tend not to spend much time tailing at the surface in the first few days after release. Understanding this is complicated though because satellite coverage is irregular and discontinuous, so disentangling marlin behaviour from satellite coverage is tricky. We also know that tagged striped marlin typically swim 1–2 km/hr but are capable of speeds in excess of 30km/hr for brief periods. Interpreting the maximum speed information is again tricky due to irregular satellite coverage, and the inherent uncertainties in location estimates (plus or minus 150 to 1000m). New fast acquisition GSP tags are available but are too large for tail mounting at this stage.

Further work is underway on this information to help researchers and managers

Furthermore, computer modeling has become an important approach to understanding pelagic fisheries. Satellite tag data have revolutionized pelagic fisheries science. However, the analytical methods for maximizing the value of these excellent data are currently evolving. International studies have recently been able to correlate a range of environmental factors with the behaviour of tunas, sharks, birds and marine mammals. We are currently learning and developing techniques to use the striped marlin satellite tagging data gathered in these studies to robustly relate marlin movement and behaviour to environmental cues no matter where in the world they are. We should eventually be able to explain much of their behaviour with confidence whether they are here in New Zealand or Fiji or Tahiti.

In addition to being the object of admiration of many recreational fishers, striped marlin are also subject to many global challenges which highlight the need for scientists, fishery managers, and fishers themselves to cooperate. This striped marlin research is an elegant example of this in action. The support of New Zealand’s recreational fishing community for the New Zealand Marine Research Foundation has enabled scientists to gather the best data possible to study one of our most important recreational fisheries, and this will in turn lead to sound scientific advice that ensures our fisheries are managed sustainably.

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