Ecology and predator-prey dynamics of Fishes at Palmyra and Kingman Atolls NWR



Trip Report from December 2008 Pangaea Research Expedition

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Executive Summary

We collected catch and effort data on bonefish catch and release activities conducted at Palmyra Atoll aboard the M/V Pangaea in December 2008. We also examined the movement patterns, recruitment dynamics, and fisheries ecology of nearshore fishes in the northern Line Islands (Christmas, Fanning, Palmyra, and Kingman atolls). Passive acoustic tracking was used to examine the spatial and temporal patterns in habitat use of several important lagoon fish species. The existing acoustic receiver array at Palmyra Atoll was upgraded and expanded to 14 receivers and a new array of 4 receivers was deployed inside the lagoon at Kingman Atoll. Bonefish (n = 17), giant trevally (n = 18), and twinspot snapper (n = 9) were acoustically tagged at Palmyra, while twinspot snapper (n = 10) were also tagged at Kingman. SPOT5 satellite tags were attached to 4 blacktip reef sharks at Palmyra to examine larger-scale habitat utilization patterns and potential inter-atoll movement. Collections of new recruits and young-of-year wrasses and damselfishes were conducted at all 4 atolls to better understand the patterns of retention and connectivity of fishes among these locations. Information was collected on the fishing catch and effort for bonefish at Palmyra to examine size structure and relative population abundance within the atoll.

- A total of 198 bonefish were caught and released in 59.3 rod hours of fishing. Catch per unit effort (CPUE) averaged 3.4 (±2.5 sd) per rod hour. The highest CPUE was recorded at the Bunker in the east lagoon (11.0 bonefish per rod hour), followed by North Beach (6.7 bonefish per rod hour), and Sixes (6.5 bonefish per rod hour).
- 17 bonefish (*Albula glossodonta*) ranging in size from 35.5 to 59.3 cm FL (mean = 45.3) were tagged with acoustic transmitters at Palmyra
- 18 giant trevally (*Caranx ignobilis*) ranging in size from 49.4 to 92.2 cm FL (mean = 67.9) were tagged with acoustic transmitters at Palmyra. Six of these tags were pressure (depth) sensitive.
- 9 twinspot snappers (*Lutjanus bohar*) ranging in size from 35.5 to 59.3 cm FL (mean = 45.3) were tagged with acoustic transmitters at Palmyra.
- 10 twinspot snappers (*Lutjanus bohar*) ranging in size from 42.5 to 65.8 cm FL (mean = 54.9) were tagged with acoustic transmitters at Kingman.
- 4 blacktip reef shark (*Carcharhinus melanopterus*) (>119 cm TL) were tagged with SPOT5 satellite tags at Palmyra.
- 14 additional blacktips were captured, measured, and tagged with conventional external spaghetti tags.
- 1 previously tagged blacktip was recaptured and several others were observed on the flats.
- 13 acoustic receivers were recovered and downloaded at Palmyra. The array was upgraded with 7 new VR2w receivers and expanded to the outer channel for a total of 14 receivers.
- 4 acoustic receivers were deployed in the lagoon at Kingman Atoll.
- 115 bluntheaded wrasses (*Thalassoma amblycephalum*) and 43 chocolate dip chromis (*Chromis margaritifer*) recruits and young-of-year were collected at the 4 atolls.

Overall, the Pangaea expedition was a great success. The collaboration between researchers and fisherman enabled us to tag more individual fish than any other previous single trip. In all, we tagged 54 fish with acoustic transmitters and 4 sharks with SPOT satellite tags. By collaborating with fishermen, we are now, for the first time, able to tag multiple species contemporaneously. This is the only way to understand complex interactions among species and between species and their environments.

INTRODUCTION

We have been conducting research into the population dynamics of bonefish and associated species at Palmyra since 2002 (Friedlander et al. 2003, 2004, 2007). Our findings to date have helped to describe the dynamics of this unique ecosystem, which is relatively free of human influences. Results show that the population of bonefish at Palmyra is likely comprised of a single species (*Albula glossodonta*) and the population size is much larger than previously estimated (10,000s-100,000s). Comprehensive logbook and tagging programs for recreational anglers between 2002 and 2004 showed large variations in catch rates by location, angler expertise, and time of year but no apparent trends over time in catch rates were detected. We also collected information on age, growth, feeding habitats, reproduction, recruitment, genetics, blood chemistry, and movement patterns of bonefish and associated species at Palmyra (Friedlander et al. 2007). These findings have provided us with a much better understanding of the ecology and species interactions that are occurring at Palmyra, which will ultimately lead to better management of resources both within the Refuge and at other coral reef ecosystems.

The information collected to date has raised a number of important resource management questions that will benefit from our existing data and knowledge. We determined bonefish at Palmyra to have much higher natural mortality rates compared with other locations that have been investigated (Friedlander et al. 2004, 2007), most likely a consequence of the large number of apex predators at Palmyra (e.g. sharks and jacks). These predator-dominated ecosystems are rare owing to the extirpation of large apex-predators from most reefs worldwide (Friedlander and DeMartini 2002, Sandin et al. 2008). Understanding the role that sharks and other apex predators play is becoming even more important due to recent reports that predator populations are declining due to over-fishing, and it is unclear what effect this may have on prey populations and other dynamics of the marine communities (Baum et al., 2003). It has become clear that in studying single species we are likely missing the critical interactions that are truly driving community patterns and our research is moving towards multi-species studies to remedy this problem.

In addition to bonefish, we have intensively studied movements and feeding habits of the most common predator in the lagoon ecosystem at Palmyra, the blacktip reef shark (*Carcharhinus melanopterus*). Our data indicates that blacktip reef sharks show site fidelity to certain lagoon areas, and that movements are focused along the edges of the sand flats (Papastamatiou et al. in press). Using fractal analysis, we surmised that blacktips patrol these edges to intercept prey species that may move to and from the lagoons and sand flats with the tides. The only other study of movement patterns of blacktip reef sharks, at Aldabra atoll, Indian Ocean, also suggested that blacktips showed site fidelity to core areas of a reef, and that movement patterns were influenced by tidal currents (Stevens 1984). Bonefish, on the other hand, appear to be using the entire lagoon over a small number of tidal cycles. A better understanding of the habitat utilization patterns of a variety of species will be useful for resource managers in designing spatially and temporally explicit management strategies.

Our recent research has indicated that blacktip reef sharks at Palmyra consume sea birds as part of their diet. This is evident based on cursory non-lethal dietary analyses of blacktip sharks as well as stable isotope analysis. Since Palmyra has considerable nesting habitat for sea birds such as terns and boobies and Kingman Atoll does not, comparing diet and behavior of sharks between these two environments would provide valuable information as to how terrestrial habitats influence the diet and trophics of apex marine predators in these pristine remote locations. Satellite and acoustic tags will tell us about the range of movement of sharks at each location and help determine if there is any inter-atoll movement. Predators are more abundant at Kingman and if they are isolated from Palmyra, we might predict different prey responses at the two locations. If Kingman and Palmyra act as one system, that would be important to know. In terms of USFWS, it would be helpful to know whether or not they can 'manage' Kingman and Palmyra as one system or not.

OBJECTIVES

Overall long-term objectives:

- Determine the spatial and temporal patterns of movement and habitat utilization of both predators and prey (including sharks, jacks, snappers, and bonefish) to elucidate species interactions and ecosystem dynamics within and between atolls.

- Determine the importance of local retention of fish larvae on Palmyra atoll versus delivery of larvae from other islands or atolls to better understand the drivers of fish population persistence and abundance on Palmyra Atoll.

Specific goals of December Pangaea expedition:

1. Continue studies of long-term movement patterns of select fishes including sharks, jacks, and bonefish at Palmyra, and include a new species, the twinspot snapper (*Lutjanus bohar*). Expand existing studies by deploying new monitors in other habitats and to Kingman Atoll.

2. Determine if there is any inter-atoll movement of reef blacktip sharks between Palmyra and Kingman. Determine differences, if any, in habitat use by blacktip reef sharks between Palmyra and Kingman.

3. Determine whether variation in larval traits and/or trace element content might be used to identify local retention of reef fish larvae to Palmyra Atoll or whether we can identify linkages among islands of Palmyra, Kiribati and Kingman reef.

RESULTS

Acoustic receivers

An array of 13 VR2 acoustic receivers has been moored throughout the lagoons at Palmyra for several years to provide information on spatial and temporal movement patterns of acoustically tagged fishes within the lagoons (Fig. 1, Appendix Table I). Using this array we have found that blacktip reef sharks show some site fidelity to certain lagoon areas, and that movements are influenced by tidal inundation of the vast reef flats surrounding the atoll. The focus of the current research is to examine the movement patterns and habitat utilization of other predator (giant trevally, *Caranx ignobilis*, and twinspot snapper) and prey species (bonefish) in the lagoon at Palmyra.

Figure 1. Locations of VR2 acoustic receivers at Palmyra Atoll. Circles represent 300 m radius detection range for each receiver.

A number of the receivers had reached the end of their life expectancy and were replaced with new and improved units (VR2W, n = 7) which provide greater storage capacity, longer battery life, and faster data retrieval. One new receiver was deployed at the end of the main channel, approximately 500 m out from the Penguin Spit receiver. The current array of receivers provides nearly complete coverage of the lagoons and the next step in our research program will be to expand this array offshore and onto the outer coral reefs. An array of four VR2 receivers was deployed at Kingman reef in the lagoon adjacent to the Clam Garden area (Fig. 2, Appendix Table II). This array was designed to examine the fine-scale movement patterns of twinspot snapper. Movement patterns and site fidelity will of twinspot snapper tagged at Palmyra in the west lagoon will be compared with those tagged in the lagoon at Kingman Reef.

<u>Acoustic tagging of fishes</u>

We surgically implanted acoustic transmitters in predator (giant trevally and twinspot snapper) and prey species (bonefish) to track their movement. Fish were inverted and placed into tonic immobility, a trance like state (Henningsen 1994). Fish were surgically fitted with an acoustic transmitter (Vemco V13 or V8) inserted through a small incision in the abdominal wall into the peritoneal cavity. The incision was closed with 1 or 2 interrupted sutures of chromic gut, depending on the transmitter and incision size. All transmitters were coated in a mixture of bees wax and paraffin (1:2.3) to reduce the chance of infection and prevent an immunological response. Each fish was measured, sexed (when possible) and tagged with an external M-type tag, before being released. Bonefish were not tagged externally to reduce the risk of predation.

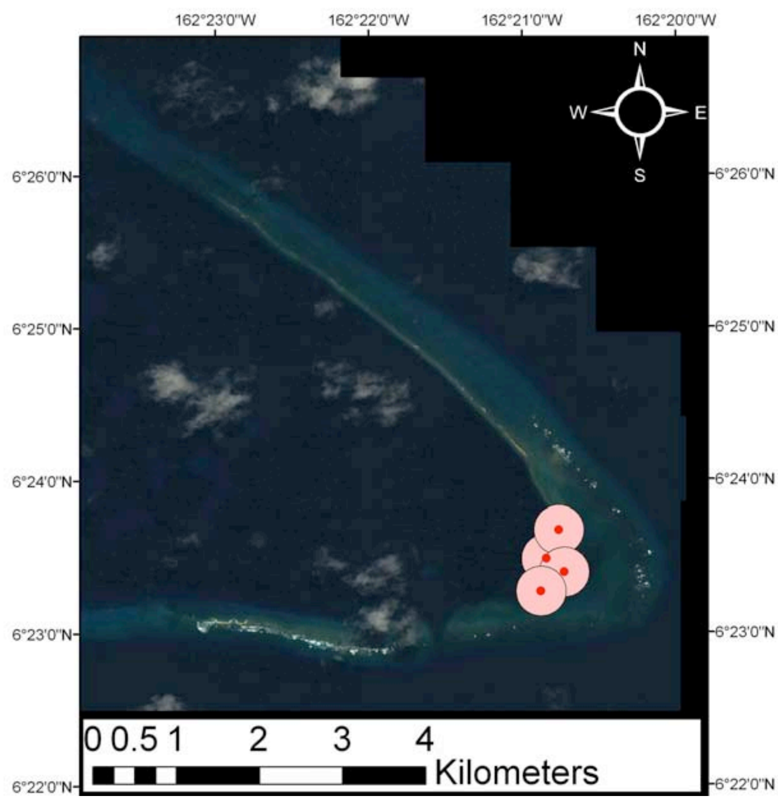


Figure 2. Locations of VR2 acoustic receivers at Kingman Atoll. 300 m buffer is represented by pink circles. Note overlap of receiver detection coverage was intended to permit examination of finer-scale movement patterns.

Bonefish (*Albula glossodonta*)
Bonefish were captured on flyrod at various locations around Palmyra and quickly placed in live wells with recirculating seawater locations in the flats boats. The fish were then transferred to a 750 gallon (2839 l) tank on shore. Seawater was pumped to this tank from the lagoon at a rate of 6 gallons/min (22.7 l/min), for a tank turnover rate of about 11.5/day. The entire system was aerated with a supplemental pump and airstone. Stocking density was ca. 5 kg/m^3 which is 1 to 2 orders of magnitude lower than typical aquaculture systems. Fish were not fed and were held for 2-5 days following surgery to allow for wound healing and physiological recovery before release. Bonefish were released both on the flats at low tide and into the deeper, central part of the Western lagoon.

Bonefish Summary Statistics

A total of 17 bonefish were captured and surgically implanted with acoustic transmitters. The mean size of bonefish was 45.3 FL cm and ranged in size from 35.5 to 59.3 cm (Figure 3, Appendix Table III)

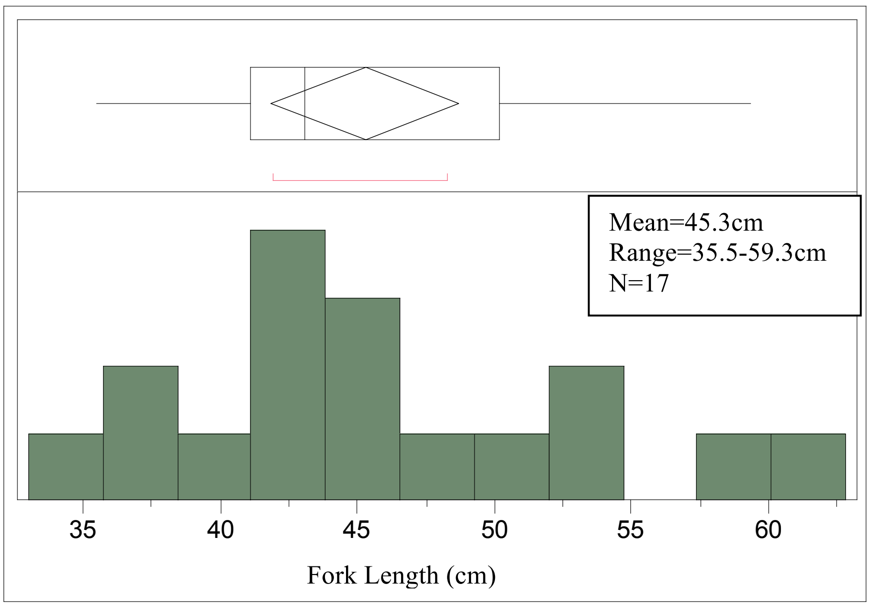


Figure 3. Length (FL cm) distribution statistics for bonefish (*Albula glossodonta*) surgically implanted with acoustic transmitters.

Figure 4. Holding tank for bonefish at the Palmyra lab.

Giant Trevally (*Caranx ignobilis*)
Giant trevally were caught using handlines while anchored, handlines and rod and reel while trolling (both during the day) and rod and reel at night off the deck of the Pangaea at Palmrya. All fish were brought onto the boat and surgery took place immediately. Fish were released following surgery to the location of capture. After several days of exploratory fishing and diving, no giant trevally were seen or caught at Kingman Reef.

Giant Trevally Summary Statistics
Eighteen giant trevally ranging in size from 49.4 to 92.2 cm FL (mean = 67.9) were tagged with acoustic transmitters at Palmyra Atoll (Figure 5, Appendix Table IV). Six of these 18 tags were fitted with pressure sensitive depth transmitters that will relay ID code number and each fish's depth (m).

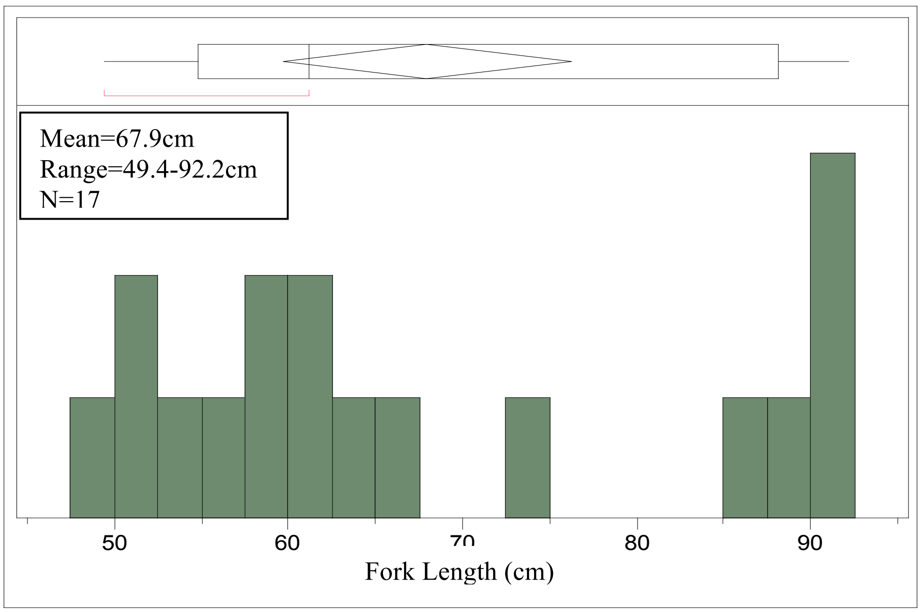


Figure 5. Length (FL cm) distribution statistics for giant trevally (*Caranx ignobilis*) surgically implanted with acoustic transmitters.

Figure 6. Surgical procedure for implantation of acoustic transmitter in giant trevally, *Caranx ignobilis*.

Twinspot snapper (*Lutjanus bohar*)

Twinspot are an important predator that accounts for 17.8% of the total biomass at Palmyra Atoll and 17.5% at Kingman Atoll (DeMartini at al. 2008). Nine twinspot snapper were caught by line fishing at Palmyra Atoll and 10 by line and flyrod at Kingman Atoll. Twinspot snappers (*Lutjanus bohar*) ranged in size from 35.5 to 59.3 cm FL (mean = 45.3) at Palmyra (Figure 7, Appendix Table V) and from 42.5 to 65.8 cm FL (mean = 54.9) at Kingman (Figure 8, Appendix Table VI). There was no significant difference in the size of twinspot snapper between Palmyra and Kingman (t = 0.09, p = 0.39).

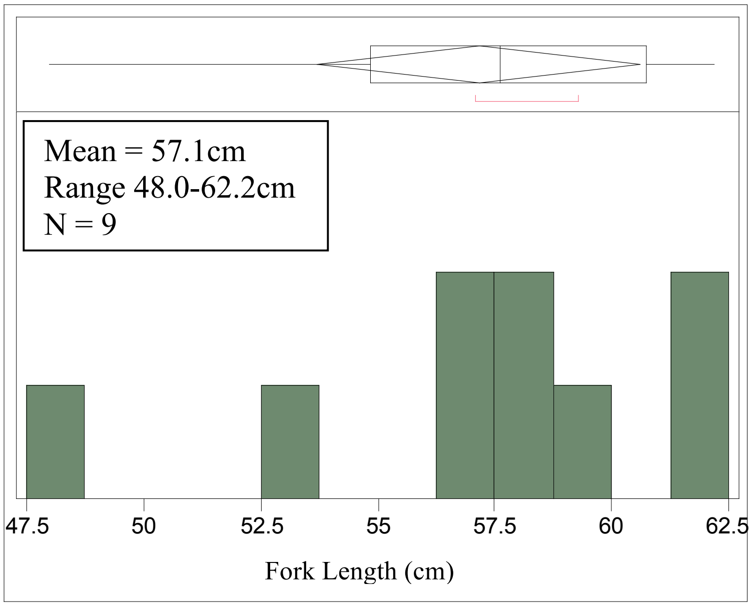


Figure 7. Length (FL cm) distribution statistics for Twinspot snapper (*Lutjanus bohar*) surgically implanted with acoustic transmitters at Palmyra Atoll.

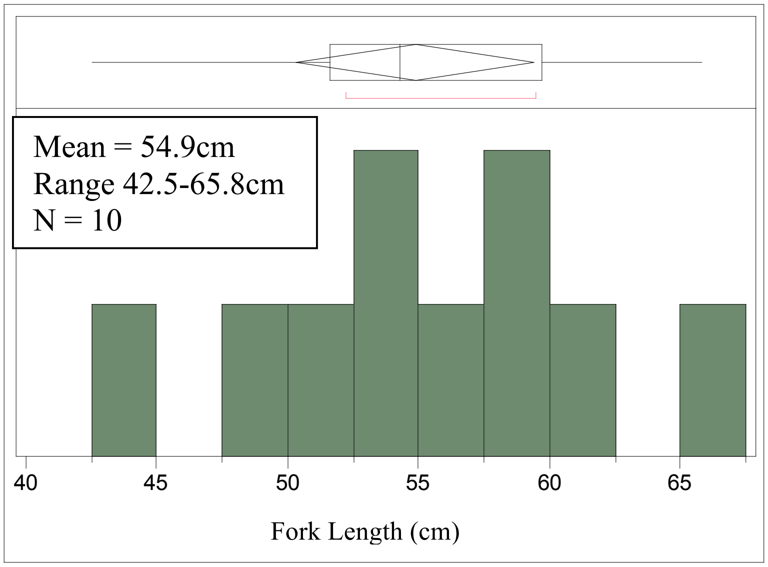


Figure 8. Length (FL cm) distribution statistics for Twinspot snapper (*Lutjanus bohar*) surgically implanted with acoustic transmitters at Kingman Atoll.

Blacktip reef shark (*Carcharhinus melanopterus*)
To examine movement rates and use of various habitats of blacktips at Palmyra, we attached small Wildlife Computers (SPOT5) satellite transmitters to the dorsal fins of 4 adult blacktips (> 119 cm TL) (Fig. 10). These tags provide geoposition information via ARGOS satellites. This will provide information on movement patterns and will indicate whether there is any movement of blacktips between Palmyra Atoll and Kingman Reef. Class positional accuracy from the satellite data varies greatly, particularly near the equator where there is lower satellite density. We obtained numerous satellite hits in the short time since deployment, but only plotted hits with positional accuracy < 500 m (Fig. 11).

We captured a total of 18 blacktips, ranging in size from 86.0 to 123.3 TL cm (mean = 109.1) (Figure 9, Appendix Table VII). One previously tagged blacktip was recaptured but the tag had been clipped off and was not readable. Several other tagged sharks were observed on the flats.

Divers spent several hours searching for blacktips along the shallow reef crest and around the islands at Kingman Reef; however, no blacktip reef sharks were seen on any dives. This is likely due to two factors: 1) lack of suitable habitat (extensive sand flats and turbid lagoons) and 2) very high densities of larger, more aggressive grey reef sharks.

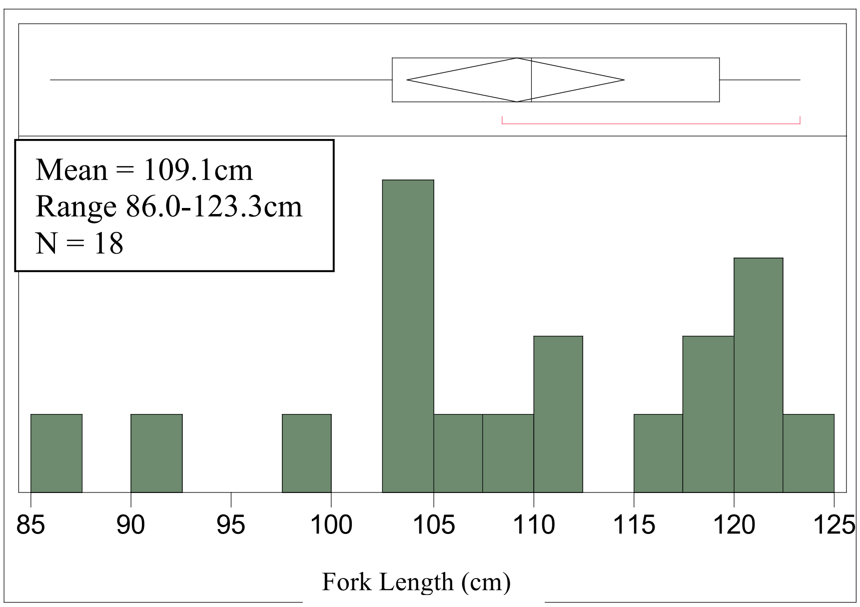


Figure 9. Length (FL cm) distribution statistics for Blacktip reef shark (***Carcharhinus melanopterus***) tagged with standard ID tags at Palmyra Atoll.

Figure 10. Installation of SPOT5 satellite tag on 119 TL cm blacktip reef shark (***Carcharhinus melanopterus***) at Palmyra on 19 December 2008.

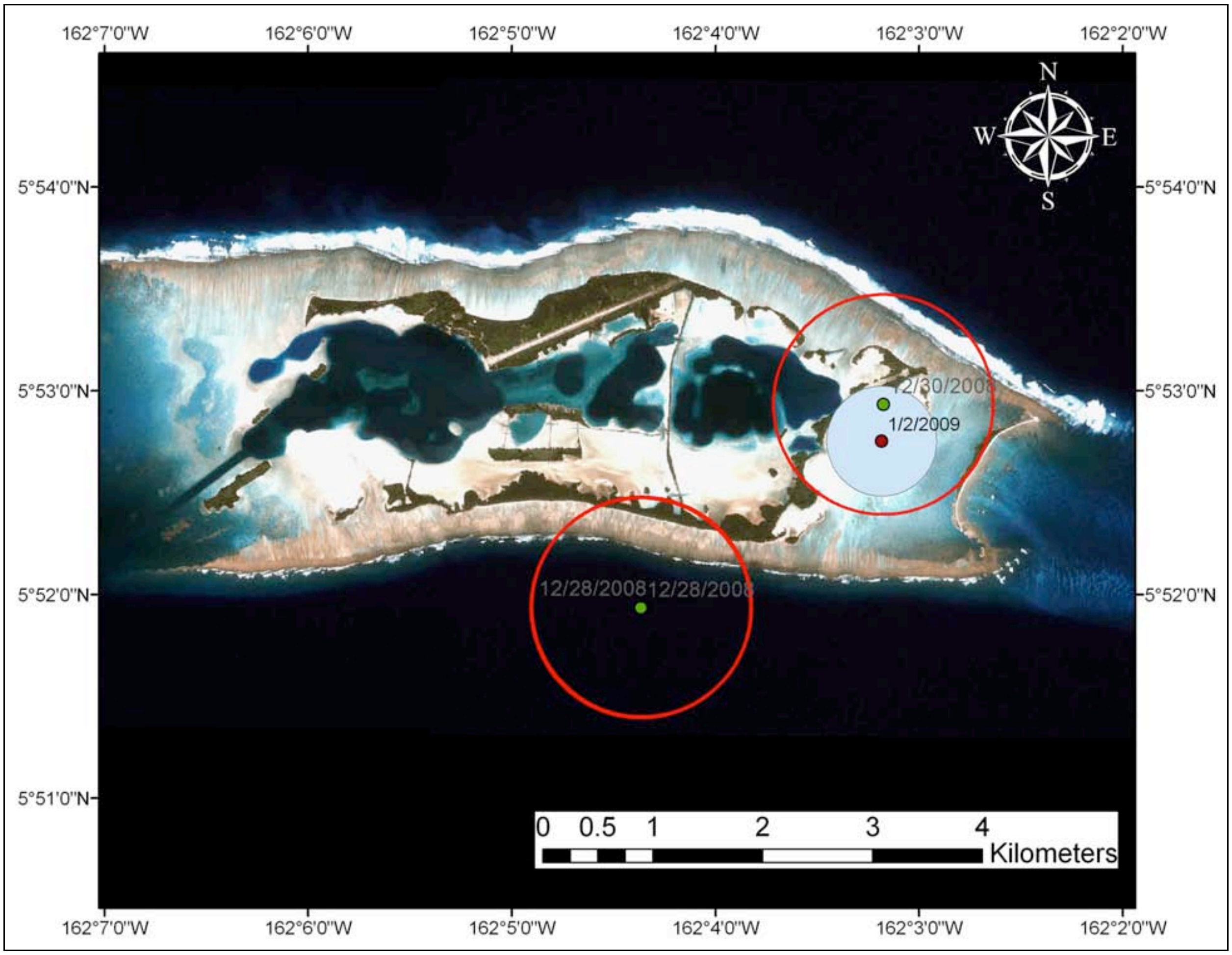


Figure 11. SPOT5 satellite tag 89368 locations for blacktip reef shark (*Carcharhinus melanopterus*) tagged in the east lagoon on 12/19/08 at 15:15. This female shark was 94.5 PCL, 103.8 FL, and 121.5 TL and was caught on flyrod at lat = 5.52.782 and long = 162.03.635. Red circles represent satellite hits with positional accuracy of ca. 1km and the blue shaded circle represents a hit with positional accuracy for < 500 m.

Bonefish fishing

A total of 198 bonefish were caught in 59.3 rod hours of fishing. Catch per unit effort (CPUE) averaged 3.4 (± 2.5 SD) per rod hour (Table 1 and Table 2). The highest CPUE was recorded at the Bunker in the east lagoon (11.0 bonefish per rod hour), followed by North Beach (6.7 bonefish per rod hour), and Sixes (6.5 bonefish per rod hour).

Table 1. Bonefish catch per unit effort (CPUE) among locations at Palmyra Atoll.

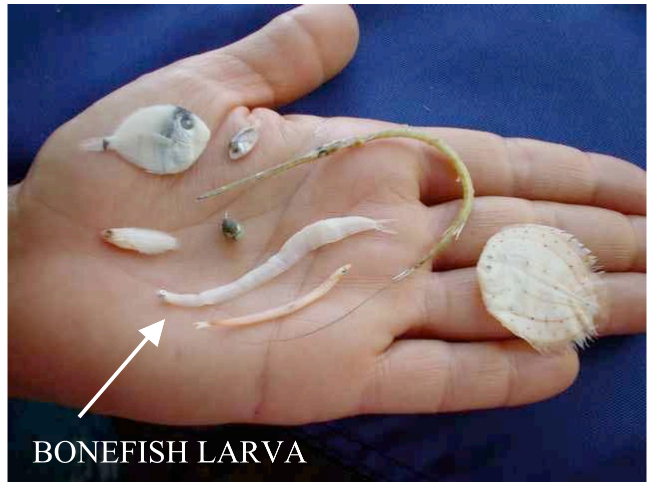
LOCATION	MEAN CPUE (FISH / ROD HR)	SD	N
Bunker	11.00		1
North Beach	6.67		1
Sixes	6.50	0.71	2
Smitty's	4.40	2.67	4
Down East	3.33		1
Nursery	3.15	1.41	7
Banjos	2.58	0.72	3
Big Eddies	2.42	1.69	6
Mary Janes	2.00		1
Edge	1.50	2.12	2
Far East	0.67	0.94	2

Table 2. Fishing effort data from bonefish catch & release fishing conducted at Palmyra Atoll in December 2008. No. of rods indicates the number of anglers per fishing period, start and stop times of day indicated the time period over which fishing occurred. CPUE represents catch per unit effort in the number of bonefish per rod hour.

DATE	LOCATION	NO. OF RODS	START TIME OF DAY	STOP TIME OF DAY	TIME FISHED (H:MM)	TOTAL HRS FISHED	BONEFISH CAUGHT	CPUE
12/9/2008	Smitty's	2	12:30	15:30	3:00	3.00	22	7.33
12/9/2008	Nursery	1	11:30	15:00	3:30	3.50	11	3.14
12/9/2008	Nursery	1	11:00	16:00	5:00	5.00	13	2.60
12/9/2008	Banjos	1	13:00	17:00	4:00	4.00	7	1.75
12/9/2008	Big Eddies	1	17:00	18:00	1:00	1.00	3	3.00
12/9/2008	Bunker	1	15:30	15:45	0:15	0.25	11	44.00
12/10/2008	Far East	2	11:00	12:30	1:30	1.50	4	2.67
12/10/2008	Smitty's	1	12:30	15:30	3:00	3.00	13	4.33
12/10/2008	Nursery	2	16:00	17:00	1:00	1.00	3	3.00
12/10/2008	Banjos	1	7:00	8:00	1:00	1.00	3	3.00
12/10/2008	Nursery	1	7:00	8:30	1:30	1.50	4	2.67
12/10/2008	Sixes	1	14:00	15:00	1:00	1.00	7	7.00
12/10/2008	Big Eddies	1	16:00	17:00	1:00	1.00	3	3.00
12/10/2008	Banjos	1	7:30	8:30	1:00	1.00	3	3.00
12/10/2008	Big Eddies	1	8:30	9:00	0:30	0.50	0	0.00
12/11/2008	Sixes	3	15:45	16:45	1:00	1.00	18	18.00
12/11/2008	North Beach	1	11:00	12:30	1:30	1.50	10	6.67
12/11/2008	Far East	1	14:30	15:30	1:00	1.00	0	0.00
12/12/2008	Big Eddies	2	15:00	16:00	1:00	1.00	3	3.00
12/12/2008	Edge	1	9:00	10:00	1:00	1.00	3	3.00
12/13/2008	Big Eddies	1	13:30	14:30	1:00	1.00	5	5.00
12/13/2008	Nursery	2	14:30	15:15	0:45	0.75	3	4.00
12/13/2008	Smitty's	2	16:00	17:15	1:15	1.25	4	3.20
12/13/2008	Edge	2	13:30	14:00	0:30	0.50	0	0.00
12/13/2008	Nursery	2	15:00	15:30	0:30	0.50	5	10.00
12/13/2008	Smitty's	2	16:00	17:00	1:00	1.00	16	16.00
12/14/2008	Nursery	2	15:30	16:40	1:10	1.17	12	10.29
12/14/2008	Mary Janes	4	17:00	17:45	0:45	0.75	6	8.00
12/14/2008	Big Eddies	1	16:30	17:00	0:30	0.50	1	2.00
12/14/2008	Down East	1	16:00	17:30	1:30	1.50	5	3.33

RECRUITMENT DYNAMICS

Background: One of the least understood and most fundamental processes in the determination of population abundance and community structure in marine ecosystems is dispersal, or transport of larvae. To what extent are local adult population dynamics influenced by the dispersal of larvae from neighboring or distant source populations? Do self-recruiting populations exist? How far do larvae disperse? The sources and destinations of larvae have been unknown for nearly all commercially and recreationally important fished species, and seemingly unknowable, and yet any model of resource management or biodiversity preservation depends on certain assumptions about transport and connectivity between marine populations. For example, do fish populations in Palmyra depend on other islands for supply of larvae? Palmyra is a very isolated atoll. Thus, local reproductive output may play a more important role in determining local dynamics than in more connected systems.



The small size and long duration of most marine animal larvae have made studies of dispersal difficult. Small animals usually cannot be burdened with tags, and the huge numbers and potentially widespread dispersal of larvae make the recovery of tags problematic. One approach involves the use and interpretation of environmental markers. The marine environment can be exceptionally heterogeneous in terms of its physical, chemical, and biological properties (e.g., Donat and Bruland, 1995; Hutchins et al., 1995). Larvae distributed among water masses with distinctly different environmental characteristics are likely to develop structural (e.g. morphological, elemental, growth rate) differences due to the differences in the environments experienced during larval growth. An environmental marker (such as trace elements incorporated into larval fish) is obtained continuously and locally from the water and can be used to retrace an individual's geographic history as it moves through different water masses.

Considerable recent progress has been made using otoliths, the balance structures in the inner ear of teleost fishes, as recorders of larval growth history and trace element environmental signatures (Campana, 1999; Jones et al., 1999; Swearer et al., 1999; Thorrold et al., 2001). It has also been known for many years that the composition and amounts of trace metals changes from place to place in the ocean, and otolith trace-element content has been used for stock identification for decades (Campana and Thorrold 2001). In this study, we ask whether trace element content might be used to identify local retention of reef fish larvae to Palmyra Atoll or whether we can identify linkages among islands of Palmyra, Kiribati and Kingman reef.

Our overall goal is to use larval and recruit biology to understand the patterns of retention and connectivity of reef fishes in open oceanic systems and to understand the importance of post-settlement processes and the interaction between habitat (including lagoons) and ecological processes in determining population sizes and community structure of fishes on Palmyra. This type of information will be critical for management, and we intend our results to aid in management of the Palmyra and Kingman NWRs.

Methods and Results: The Pangaea expedition marked the beginning of a focused research effort in this area. We were able to collect recruits (i.e. newly settled reef fishes) of two species at all islands visited (Table 3). These fish will be brought back to the lab where we will dissect their otoliths. From the otolith we will measure growth rates during the planktonic larval phase and the number of days these fish spent as larvae (planktonic larval duration). We hypothesize that if Palmyra Atoll is self-seeding, larvae staying nears the island (perhaps even in the lagoons) may have a different planktonic larval duration and/or growth rates than larvae that are traveling about in open ocean currents from island to island. We will then analyze the chemical signature of the otoliths and compare among islands.

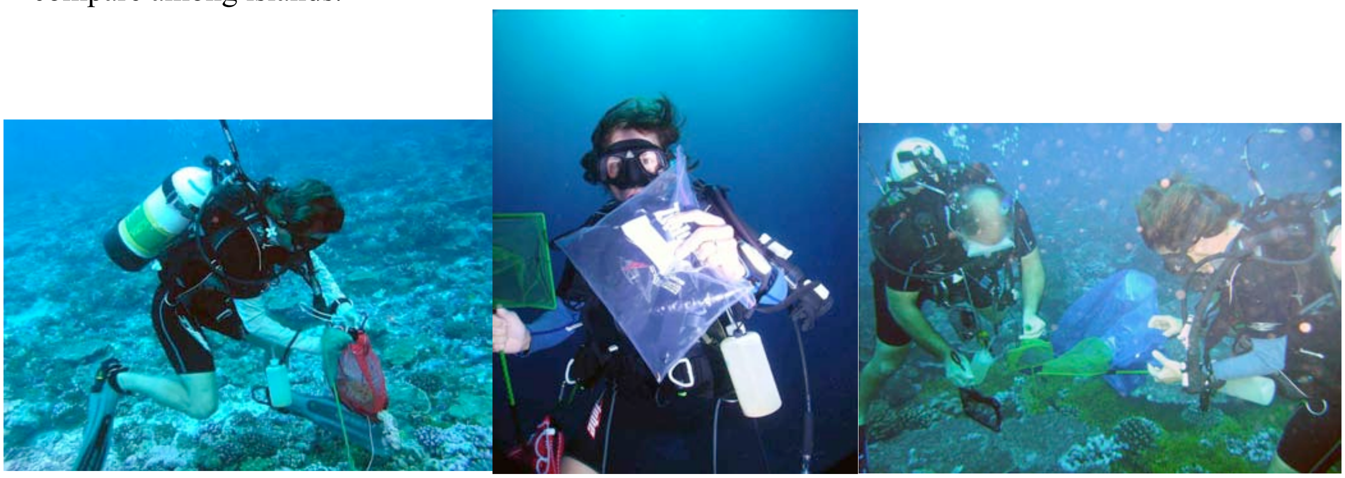


Figure 12. Collecting fish recruits at Palmyra, Kingman and Kirimati Atolls.

Table 3. Numbers of recruit fish collected on the December Pangaea trip.

SPECIES	CHRISTMAS ATOLL	FANNING ATOLL	PALMYRA ATOLL	KINGMAN ATOLL
Thalassoma <u>amblycephalum</u> 	28	19	32	36
Chromis margaritifer 	0	13	25	5

CONCLUSIONS

Overall, the Pangaea expedition was a great success. The collaboration between researchers and fisherman enabled us to tag more individual fish than any other previous single trip. In all, we tagged 54 fish with acoustic transmitters and 4 sharks with SPOT satellite tags. By collaborating with fishermen, we are now, for the first time, able to tag multiple species contemporaneously. This is the only way to understand complex interactions among species and between species and their environments.

Despite great effort, no blacktip reef sharks or giant trevally were seen and therefore tagged at Kingman Reef. Because twinspot snapper and grey reef sharks appear to be the dominant predators in the lagoon at Kingman, tagging was focused on twinspot snapper to allow for comparisons with Palmyra. It will be interesting to see how this species uses the lagoon habitats at each location and whether the lack of blacktip reef sharks and increased abundance of grey reef sharks at Kingman influences the movements of twinspot snapper.

Future sampling: We anticipate visiting Palmyra Atoll sometime in the spring or early summer of 2009 to download the receivers and continue the fish recruitment surveys. In the late fall or early winter 2009, we hope to collaborate again with the Pangaea and to be able to visit Kingman in order to download the receivers we have moored there. Based on the results from the downloads, we will continue tagging individuals of the same species and/or additional lagoon species (including mullet, bluefin trevally, and milkfish). Further, we hope to expand the receiver array to the outer reef and begin comparisons between species that inhabit both habitats (e.g. blacktip reef sharks and twin spot snapper).

ACKNOWLEDGEMENTS

We would like to sincerely thank the owners, friends, guides and crew of the M/V Pangaea, without whom we would never have accomplished this work. We also would like to thank the International Game Fish Association and Jason Schratwieser for funding and fishing for this project. Additional funding came from the Marisla Foundation.

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APPENDIX TABLES

Table I. Geographic coordinates for acoustic receivers at Palmyra Atoll.

STATION	LONG	LAT	LOC_NAME
1	-162.0910	5.8854	Alans_mound
2	-162.0940	5.8817	Inner_eddies
3	-162.1056	5.8781	Barge
4	-162.0795	5.8845	Jens_addiction
5	-162.1111	5.8730	Outer_channel
6	-162.1150	5.8704	Out_out_channel
7	-162.0887	5.8787	Nursery
8	-162.0996	5.8805	Big Eddies
9	-162.0971	5.8871	Banjos
10	-162.0850	5.8836	Airport
11	-162.0712	5.8874	Mid-channel
12	-162.0626	5.8860	Cookies
13	-162.0654	5.8802	Sixes
14	-162.0605	5.8830	Down East

Table II. Locations of VR2 acoustic receivers deployed at Kingman reef.

VR2#	LOCATION	LAT	LONG	DEPLOYMENT DATE	DEPLOYMENT TIME
2232	Clam Patch	793425	707226	17-Dec-08	13:20
2229	Clam North	793574	707573	17-Dec-08	13:45
2231	Clam Middle	793639	707064	17-Dec-08	14:20
2233	Clam South	793360	706833	17-Dec-08	15:50

Table III. Summary statistics for bonefish surgically implanted with acoustic transmitters at Palmyra Atoll.

DATE	VEMCO SS#	ACOUSTIC TAG CODE	TRANSMITTER TYPE	FL (CM)	NOTES
13-Dec-08	1062175	53984	V9-2L-R64K	52.4	Tagged on 11-Dec-2008
13-Dec-08	1062183	53993	V9-2L-R64K	56.2	Tagged on 11-Dec-2009
13-Dec-08	1062178	53987	V9-2L-R64K	45	Tagged on 11-Dec-2010
13-Dec-08	1062170	53979	V9-2L-R64K	37.7	Tagged on 11-Dec-2011
13-Dec-08	1062180	53990	V9-2L-R64K	48.3	Tagged on 11-Dec-2012
13-Dec-08	1062181	53991	V9-2L-R64K	35.5	Tagged on 11-Dec-2013
13-Dec-08	1062176	53985	V9-2L-R64K	41.9	Tagged on 11-Dec-2014
13-Dec-08	1062182	53992	V9-2L-R64K	42.3	Tagged on 11-Dec-2015
13-Dec-08	1062174	53983	V9-2L-R64K	40.3	Tagged on 11-Dec-2016
15-Dec-08	1062132	53998	V13-1L-R64K	59.3	Tagged on 14-Dec-2008
15-Dec-08	1062129	53995	V13-1L-R64K	52.1	Tagged on 14-Dec-2009
15-Dec-08	1062169	53978	V9-2L-R64K	48	Tagged on 14-Dec-2010
15-Dec-08	1062171	53980	V9-2L-R64K	44.5	Tagged on 14-Dec-2011
15-Dec-08	1062179	53989	V9-2L-R64K	42.8	Tagged on 14-Dec-2012
15-Dec-08	1062172	53981	V9-2L-R64K	43.1	Tagged on 14-Dec-2013
15-Dec-08	1062177	53986	V9-2L-R64K	37.8	Tagged on 14-Dec-2014
20-Dec-08	1062173	53982	V9-2L-R64K	42.7	caught east lagoon, held for 1 day, surgery, released at Banjos

Table IV. Summary statistics for giant trevally captured and tagged with acoustic transmitters at Palmyra Atoll.

DATE	TAG LOCATION	TIME	VEMCO SS#	ACOUSTIC TAG CODE	TRANSMITTER TYPE	EXTERNAL TAG NO.	FL	METHOD	LAT	LONG
12/11/08	Dudley	13:05	1062164	158/14563	V13P-1L-S256	5754	55.5	Handline	5.88444	162.0986
12/11/08	Lesley	15:15	1062165	159/14564	V13P-1L-S256K	5751	50	Handline	5.88056	162.10335
12/12/08	W. Lesley	12:20	1062130	53996	V13-1L-R64K	5756	59.5	Handline	5.88421	162.1006
12/12/08	W. Lesley	13:30	1062128	53994	V13-1L-R64K	5755	51.5	Handline	5.88012	162.10471
12/15/08	Head of main channel	15:02	1062166	160/14565	V13P-1L-S256	5998	63.0	Handline	5.87809	162.10555
12/15/08	Off Pangaea	19:32	1062133	53999	V13-1L-R64K	5996	65.3	Handline	5.885906	162.08745
12/15/08	Off Pangaea	21:00	1062137	54004	V13-1L-R64K	5995	61.0	Pole	5.885906	162.08745
12/16/08	Off Pangaea	21:15	1062168	162/14567	V13P-1L-S256	5994	61.2	Pole	5.885906	162.08745
12/18/08	Off Pangaea	20:55	1062163	157/14562	V13P-1L-S256	5767	63.6	Pole	5.885906	162.08745
12/19/08	CRED buoy	7:50	1062153	54020	V13-1L-R64K	5993	57.7	Trolling	5.88495	162.10357
12/19/08	Dudley	9:30	1062147	54019	V13-1L-R64K	5755	89.2	Trolling	5.88444	162.0986
12/19/08	East Lagoon	12:05	1062146	54013	V13-1L-R64K	No tag	91.2	Trolling	5.886417	162.06127
12/19/08	East lagoon	12:10	1062167	161/14566	V13P-1L-S256	No tag	92.2	Trolling	5.886417	162.06127
12/19/08	Banjos	17:35	1062150	54017	V13-1L-R64K	5982	87	Trolling	5.090004	162.56632
12/19/08	Off Pangaea	21:17	1062161	54028	V13-1L-R64K	5988	91.8	Pole	5.886483	162.0907
12/20/08	Lesley	8:51	1062148	54015	V13-1L-R64K	5981	49.4	Trolling	5.87965	162.10413
12/20/08	Eddies dolphins	9:51	1062156	54023	V13-1L-R64K	5980	54.2	Trolling	5.878083	162.09102
12/21/08	End of Lesley	17:43	1062157	54024	V13-1L-R64K	5972	74.5	Trolling	5.879167	162.11365

Table V. Summary statistics for twinspot snapper acoustically tagged at Palmyra Atoll.

DATE	TAG LOCATION	TIME	VEMCO SS#	ACOUSTIC TAG CODE	TRANSMITTER TYPE	EXTERNAL TAG NO.	FL	TL	METHOD	LAT	LONG
12/19/08	Dudley	8:05	1062151	54018	V13-1L-R64K	5758	59.3	65	Trolling	5.884433	162.09867
12/19/08	off Sand Isl in channel	7:58	1062145	54012	V13-1L-R64K	5989	57.4		Line	5.876667	162.10733
12/19/08	off Sand Isl in channel	8:10	1062152	54019	V13-1L-R64K	5991	57.6		Line	5.876667	162.10733
12/19/08	off Sand Isl in channel	8:29	1062149	54016	V13-1L-R64K	5990	62.2		Line	5.876667	162.10733
12/20/08	outer Channel (last can)	15:37	1062155	54022	V13-1L-R64K	5979	58.0		Line	5.87035	162.11502
12/21/08	outer channel	13:03	1062159	54026	V13-1L-R64K	5977	52.6	55	Line	5.872233	162.11365
12/21/08	outer channel	13:11	1062160	54027	V13-1L-R64K	5976	48.0	50	Line	5.872233	162.11365
12/21/08	mid channel	13:26	1062162	54029	V13-1L-R64K	5975	62.2	64	Line	5.872967	162.11148
12/21/08	outer channel	14:05	1062154	54021	V13-1L-R64K	5974	57.1	59	Line	5.872233	162.11365

Table VI. Summary statistics for twinspot snapper acoustically tagged at Kingman reef.

DATE	TAG LOCATION	TIME	VEMCO SS#	ACOUSTIC TAG CODE	TRANSMITTER TYPE	FL	METHOD	LAT	LONG
12/17/08	Clam patch	18:00	1062135	54001	V13-1L-R64K	49.9	flyrod	6.39139	162.34761
12/17/08	Clam North	18:10	1062142	54009	V13-1L-R64K	52.2	flyrod	6.39452	162.34625
12/18/08	Clam patch	8:27	1062131	53997	V13-1L-R64K	42.5	flyrod	6.39139	162.34761
12/18/08	Clam South	8:45	1062140	54007	V13-1L-R64K	57.5	flyrod	6.38783	162.34822
12/18/08	Clam South	8:53	1062141	54008	V13-1L-R64K	65.8	flyrod	6.38783	162.34822
12/18/08	Clam South	9:01	1062144	54011	V13-1L-R64K	59.5	flyrod	6.38783	162.34822
12/18/08	Clam South	9:08	1062134	54000	V13-1L-R64K	55.0	flyrod	6.38783	162.34822
12/18/08	Clam South	9:15	1062136	54002	V13-1L-R64K	53.5	flyrod	6.38783	162.34822
12/18/08	Clam Middle	9:24	1062138	54005	V13-1L-R64K	60.2	flyrod	6.3901	162.3456
12/18/08	Clam Middle	9:36	1062139	54006	V13-1L-R64K	52.5	flyrod	6.3901	162.3456

Table VII. Summary statistics for blacktip reef sharks caught and tagged at Palmyra Atoll. No Blacktip reef sharks were fitted with acoustic transmitters.

DATE	TAG LOCATION	SEX	TIME	SPOT5 SAT TAG PTT	DART TAG NO.	PCL	FL	TL	CLASP INSIDE	CLASP OUTER	METHOD	LAT	LONG
12/12/08	Dudley	M	12:00		5757	78	83	103	12	9	handline	5.88421	162.1006
12/12/08	W. Lesleys	M	12:30		5752	86	93.5	111.4	16.2	11	handline	5.88421	162.1006
12/12/08	W. Lesleys	F	13:55		5753	78.5	86.5	103			handline	5.88012	162.1047
12/12/08	W. Lesleys	M	14:23		4536	80	87.5	104	15.4	11.1	handline	5.88012	162.1047
12/13/08	Inner main channel	F	13:00	89369	5761	94.5	105	123.3			handline	5.87813	162.1055
12/14/08	Causeway	F	16:21		5766	82	86.8	106			handline	5.88692	162.0697
12/14/08	Causeway	F	16:25		5760	90.2	108	115.3			handline	5.88692	162.0697
12/14/08	Causeway	F	16:53		4516	85.6	95	111.6			handline	5.88692	162.0697
12/14/08	Causeway	M	17:00		5763	71.2	84	98.8	15.8	12.7	handline	5.88692	162.0697
12/14/08	Causeway	F	17:10		5762	70.4	76	90.4			handline	5.88692	162.0697
12/15/08	Head of main channel	F	13:56		5751	89	99	119			handline	5.87809	162.1056
12/15/08	Head of main channel	F	14:08		5768	81.5	88	108.5			handline	5.87809	162.1056
12/15/08	Head of main channel	F	14:13		5999	0.5	84	103.3			handline	5.87809	162.1056
12/15/08	Head of main channel	F	15:40		5997	95	105	120.6			handline	5.87809	162.1056
12/18/08	Off Pangaea 2nd anchorage		20:56	89367	5769	95.2	102	120.1			pole	5.88591	162.087
12/19/08	East lagoon	F	15:15	89368	5985	94.5	103.8	121.5			flyrod	5.52.782	162.03.635
12/19/08	East Lagoon		14:00		59	70	77	86			flyrod	5.52.782	162.03.635
12/19/08	Off Pangaea 2nd anchorage	F	21:26	89370	5987	90.2	99.8	119			pole	5.53.189	162.05.442