Animal Biotelemetry

A pilot study of deepwater fish movement with respect to marine reserves

Weng

BioMed Central

Weng *Animal Biotelemetry* 2013, **1**:17
http://www.animalbiotelemetry.com/content/1/1/17

Animal Biotelemetry

RESEARCH Open Access

A pilot study of deepwater fish movement with respect to marine reserves

Kevin C Weng

Abstract

Background: The spatial ecology of deepwater demersal teleosts is poorly understood, and this group of fishes has rarely been studied using conventional or electronic means to discern movement and migration. Likewise, the development of management tools for such species has received less attention as compared to shallow water species, and there are few fishery closed area systems developed for the purpose of managing deepwater demersal fishes. The eteline snappers, which occur in depths of 100 to 400 m, are an important fishery resource throughout the tropical Pacific, and are believed to be vulnerable to over-exploitation.

Results: Deepwater eteline snappers were tagged with acoustic transmitters and detected on a network of listening stations that encompassed a fishery closed area in the Main Hawaiian Islands. Differences were detected in movement between species, with the bentho-pelagic *Etelis coruscans* moving more frequently and over slightly longer distances (1.4 movements/day detected, interquartile range (IQR) 0.0 – 2.4; maximum distance 4.7 km, interquartile (IQR) 4.7 – 6.4 km) than the demersal *Etelis carbunculus* (0.0 movements/day detected, interquartile range 0.0 – 0.3; maximum distance 4.7 km, interquartile range 4.6 – 4.7 km). The maximum single movement distance was 8.9 km for *E. coruscans* and 4.7 km for *E. carbunculus*. The median length dimension for bottomfish closed areas in the Main Hawaiian Islands is 9.2 km (IQR) range 7.3 – 13.0 km).

Conclusions: Knowledge of the spatial ecology of animals is essential to understanding the effects of spatial management measures such as marine reserves. Differences between species indicate that effective reserve size will differ depending on the species. These results suggest that the reserves set up for bottomfish in the Main Hawaiian Islands are likely to have effects in reducing fishing mortality for *E. carbunculus* due to its low rate of cross border movement.

Keywords: Spatial ecology, Fishery management, Marine protected area, Fishery closed area, Acoustic telemetry, Eteline snapper, Bottomfish

Background

Many papers have been published on the spatial ecology of shallow water demersal fishes [1-3] and pelagic nekton [4-7], but comparatively little effort has been directed towards this aspect of the biology of deepwater demersal fishes [8-10]. Deepwater demersal fishes have a number of biological characteristics warranting close consideration for fishery management and conservation. As with many demersal species, limited home ranges [11,12] may allow for rapid declines in local populations when exploited. Many deeper living species show lower rates of somatic growth, population increase and fecundity as compared to related shallow living species [13]. Since the predictability of demersal habitats (as compared to oceanographically-defined pelagic habitats) can enhance catchability, overfishing can occur more easily.

In Hawaii, the deepwater bottomfish complex provides a regional fishery yielding high-value seafood [14]. The primary habitat of bottomfish occurs at 100–400 m depths throughout the archipelago, and the group comprises *Etelis coruscans* (onaga, scarlet snapper), *Etelis carbunculus* (ehu, red snapper), *Pristipomoides filamentosus* (opakapaka, pink snapper), *Pristipomoides sieboldii* (kalekale, lavender jobfish), *Pristipomoides zonatus* (gindai, banded snapper), *Aphareus rutilans* (lehi, rusty jobfish), and *Epinephelus quernus* (Hapuupuu, Hawaiian grouper) [15].

Correspondence: kevincmweng@gmail.com
Pelagic Fisheries Research Program, University of Hawaii at Manoa, Honolulu, HI 96822, USA

The State of Hawaii has created a series of bottomfish restricted fishing areas through the Main Hawaiian Islands [16]. The system in the Main Hawaiian Islands was created in 1998 and comprised 19 closed fishing areas to address overfishing of *Etelis coruscans* and *Etelis carbunculus*. This reserve system was amended in 2007 to the 12 areas shown in Figure 1. The goal of these amendments was to reduce bottomfishing mortality by a mandated 15%, and a more recent analysis has changed this target to 24% [17]. The bottomfish closed areas of the Main Hawaiian Islands are large (median size 85 km^2; interquartile range (IQR) 53–168 km^2) compared to shallow coral reef marine reserves in the Main Hawaiian Islands that range in size from 0.18 to 1.24 km^2 [18]. The efficacy of these reserves in reducing mortality and hence resulting in both an increase in population size and maturity status is now a key question. In order to understand how these reserves will work, we must know the movement patterns of the fish, and whether they leave and enter closed areas. The movement and home range of fishes is a critical knowledge gap for fishery managers [19,20].

Our knowledge of the spatial ecology of bottomfish is presently limited. Deepwater physoclists suffer barotrauma when rapidly brought to the surface [21-23]. Feeding transmitters to fish at depth avoids barotrauma, but species and size data may not be effectively gathered, and tags are general regurgitated after days to weeks [24].

Two conventional tagging studies and two acoustic telemetry study have been conducted in the Main Hawaiian Islands. From the late 1980s to early 1990s bottomfish were tagged using conventional external tags (Okomoto, Division of Aquatic Resources, State of Hawaii, unpublished). Most recoveries were near the tagging locations, with some inter-island movements including one *Pristipomoides filamentosus* that traveled from Penguin Banks, Molokai to Kaena Point, Oahu (Clay Tam, personal communication). A recent conventional tagging program has tagged 819 fish of which three have been recovered, all *Pristipomoides filamentosus* in the Main Hawaiian Islands (Clay Tam, Department of Land and Natural Resources, personal communication). Acoustic tracking of juvenile *Pristipomoides filamentosus* in waters off Kaneohe Bay revealed small scale crepuscular migrations as well as the unexpected use of flat silt habitat by the juvenile stage of the species [25]. An acoustic tagging study of adult and sub-adult *Pristipomoides filamentosus* in the Kahoolawe Island Reserve revealed that fish moved from shallower water during night to deeper water during day, as well as movements across the boundary of the reserve [26]. Together, these few studies show that *Pristipomoides filamentosus* move along island slopes and can move between islands, but we do not know if such movements are rare or routine.

Spillover from reserves to adjacent fished areas is of great interest to fishermen, and a body of research has emerged to determine whether fish are more numerous and larger in the vicinity of a reserve [27-30]. However, there is agreement in the scientific literature that adult spillover produces very minor increases in total yield, whereas the larvae produced by the spawning stock in a reserve can produce a major recruitment subsidy to surrounding regions [19,28,31].

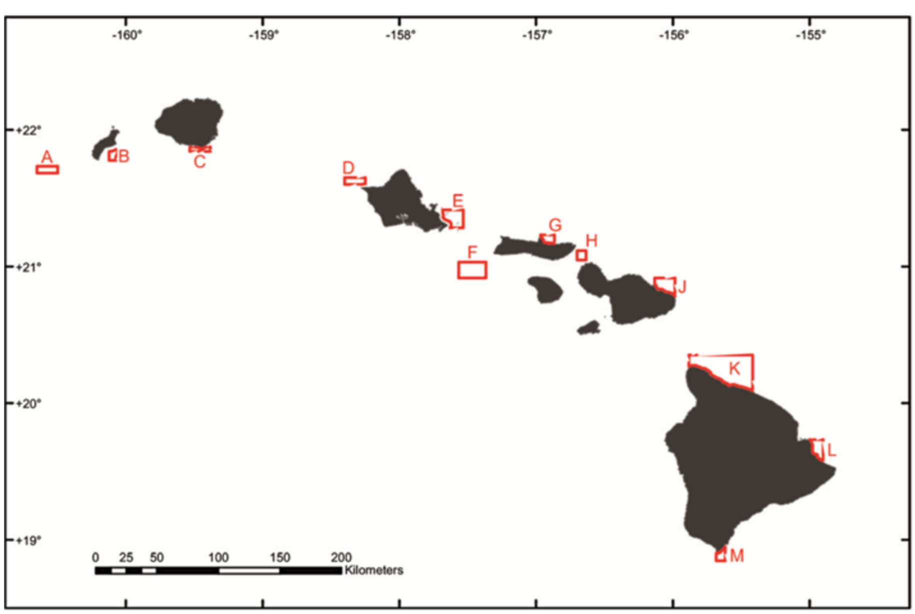

Figure 1 Areas closed to deepwater snapper fishing in Hawaii. Red boxes indicated closed areas. Letters are the closed area designations used by the State of Hawaii.

Fishing is known to cause evolutionary changes in fishes via artificial selection [32-34]. These changes depend on the nature of the fishing mortality, and since fishing frequently targets larger, older individuals, the artificial selection causes maturation at smaller size and younger age [34]. A reduction in maturity status and size in Main Hawaiian Island bottomfish has been recorded [17], so we have reason to be concerned about this process. Maintaining populations with little or no exploitation is essential to maintaining genetic diversity and genotypes for large, late-maturing traits that maximize reproductive output [32], and can be achieved with appropriately designed reserves [35]. Furthermore, there is evidence that larger, older individuals not only produce more offspring, but that their offspring have higher fitness than those of younger parents [36,37]. Populations that have reduced age and size at maturity are also likely to experience larger fluctuations in population [38], which are detrimental both ecologically and economically. Protection of a broodstock in marine protected areas can reduce variation in recruitment, resulting in more predictable population dynamics [39].

This study aimed to test the following hypotheses: (1) bottomfish routinely move across the borders of an existing fishery closed area. (2) bottomfish movements exceed the scale of individual fishery closed areas and (3) bottomfish traverse areas with depths exceeding our present definition of bottomfish habitat (400 m).

Results and discussion

Fish tagging and data recovery

Sixty-five *Etelis coruscans*, 17 *Etelis carbunculus* and three *Pristipomoides filamentosus* were tagged at locations show in Figure 2. The movements of these fish were recorded on acoustic receivers placed inside and outside of the closed area as shown in Figure 3. All acoustic receivers were successfully released from their anchors and recovered, then successfully downloaded, to yield fish movement data summarized in Table 1. Data were received for 30 *Etelis coruscans* averaging 56 cm TL, ranging from 35 to 73 cm TL; 10 *Etelis carbunculus* averaging 40 cm TL, ranging from 31 to 55 cm TL; and one *Pristipomoides filametosus* of 75 cm TL. The last species is not reported due to having an n of one.

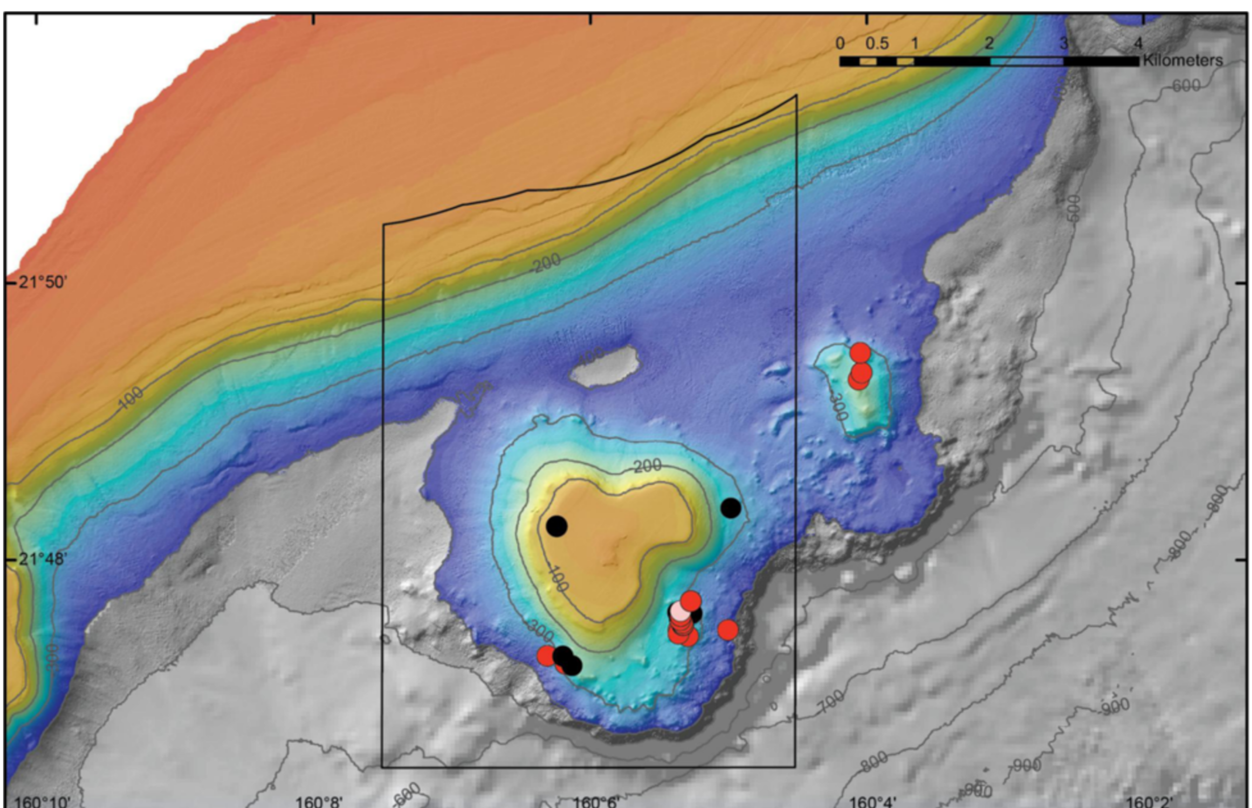

Figure 2 Tagging locations for deepwater snappers east of Niihau, Hawaii, for *Etelis coruscans* (red circles), *Etelis carbunculus* (black circles) and *Pristipomoides filamentosus* (pink circles). Black line shows boundary of bottomfish closed area B. Contours in meters, colored bathymetry for the range of bottomfish habitat (100-400 m). Bathymetry data from Hawaii Mapping Research Group / HURL.

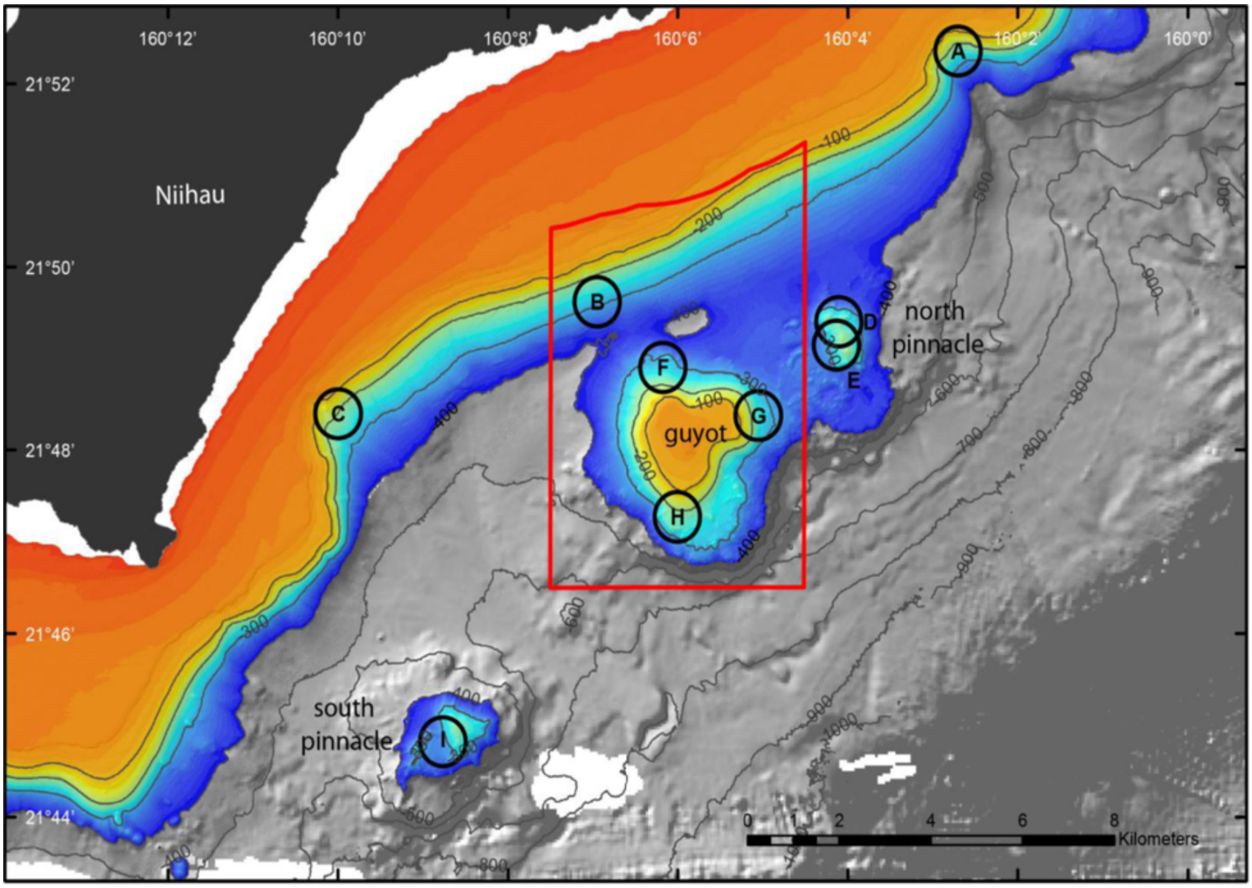

Figure 3 Location of acoustic receivers in relation to the fishery closed area and the bathymetric features within the study site. Black circles show locations of acoustic receivers, with a radius of 500 m. indicating approximate detection range. Red line shows the boundaries of the bottomfish restricted fishing area. Contours in meters, colored bathymetry for the range of bottomfish habitat (100–400 m).

Data were not received for 35 *Etelis coruscans,* seven *Etelis carbunculus* and two *Pristipomoides filametosus*. These individuals did not enter the detection zones of our receivers, and may have either died or left the study area. Fishes caught and deemed unsuitable for tagging comprised five *Etelis coruscans,* four *Etelis carbunculus* and one *Pristipomoides filametosus*.

Table 1 Tagging and data capture for eteline snappers in Hawaii

	Etelis coruscans	Etelis carbunculus	Pristipomoides filamentosus
Tagged	65	17	3
Detected on network	39	14	2
Tracks < 7 days	15	4	0
Dead	9	4	1
Remaining good tracks	15	6	1

Movements with respect to closed area

Summary data for movements are presented in Table 2. A movement was defined as a detection at one receiver, followed by a detection at a different receiver. Variability within species was high, likely because the widely spaced receiver network had a low frequency of detecting tagged fish. Longer detection records were obtained for *Etelis coruscans* than for *Etelis carbunculus* but the difference was not significant. The number of movements per day, normalized by days detected, was significantly greater for *E. coruscans* (Mann–Whitney p = 0.05), which moved slightly more than once per day, whereas *E. carbunculus* did not move on an average day (Contours in meters, colored bathymetry for the range of bottomfish habitat (100–400 m) (Figure 4).

The border crossings were greater *by E. coruscans* (Contours in meters, colored bathymetry for the range of bottomfish habitat (100–400 m) (Figure 4), with enterings to the closed area occurring slightly less than once per month, significantly greater than for *E. carbunculus*, which did not leave the closed area (Mann–Whitney p = 0.04). The difference in departures from the closed

Table 2 Summary of movements for two species of deepwater eteline snapper

	Etelis coruscans (n = 15)			Etelis carbunculus (n = 6)			
	median	**1st quartile**	**3rd quartile**	**median**	**1st quartile**	**3rd quartile**	**Mann Whitney *p***
Track days	40.83	20.59	328.42	28.44	11.90	58.52	0.46
Movements/day detected	1.44	0.03	2.38	0.00	0.00	0.33	0.05
Depart/month detected	0.00	0.00	19.50	0.00	0.00	0.00	0.06
Enter/month detected	0.77	0.00	20.86	0.00	0.00	0.00	0.04
Days inside/day detected	1.00	0.95	1.00	1.00	1.00	1.00	0.85
Days outside/day detected	0.28	0.00	0.71	0.00	0.00	0.00	0.13
Max movement distance (m)	4725	4725	6412	4725	4636	4725	0.03

area was slightly below the threshold for significance (Mann–Whitney p = 0.06).

The number of days detected inside the closed area, normalized by the number of days detected, was not significantly different between the two species, and was close to one for both, meaning that on average, most fish were inside the closed area. The number of days detected outside the closed area, normalized by the number of days detected, was greater for *E. coruscans*, but not by a significant margin. Because *E. coruscans* were tagged both inside and outside of the closed area, but *E. carbunculus* only tagged inside the closed area, a fair comparison of days outside is not possible, but the results are consistent with a low departure rate for *E. carbunculus.*

Our results suggest that *E. coru*scans moves more frequently and over greater distances than *E. carbunculus*. As a result, the level of protection afforded by the closed area is likely to be greater for *E. carbunculus*. However,

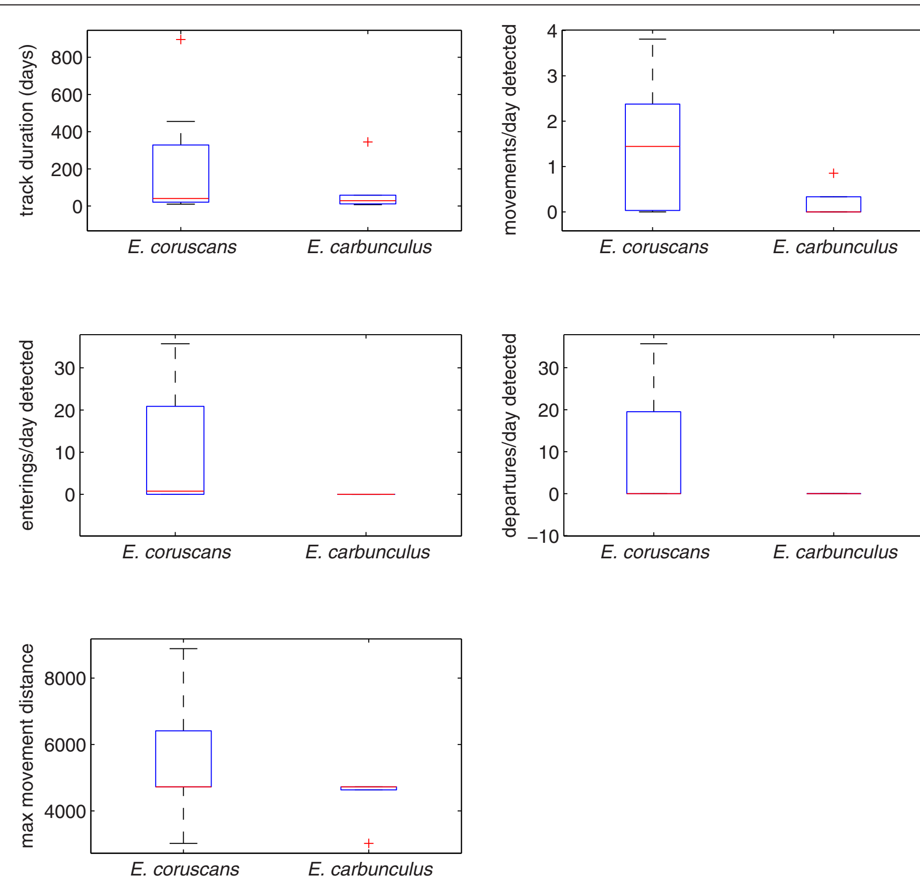

Figure 4 Comparison of track duration (days from tagging to last detection), movements, closed area border-crossings and maximum movement distances between two species of deepwater eteline snapper.

the number of border crossings per month was still low for *E. coruscans* indicating that the closed area likely has an effect for this species.

Movement distances and frequencies

The maximum single movement distance was 8.9 km for *E. coruscans* and 4.7 km for *E. carbunculus*. Across all individuals the maximum movement distance was significantly greater for *E. coruscans* (Mann–Whitney p = 0.03; Contours in meters, colored bathymetry for the range of bottomfish habitat (100–400 m) (Figure 4). The median movement distances were similar for *E. coruscans* and *E. carbunculus* (2.1 km and 2.6 km respectively). The median movement distance was similar in scale to the meridional length of the closed area (5.2 km) for both species. As a result, the closed area appears to be of sufficient size to offer some protection to both species, though the higher frequency of movement for *E. coruscans* must be taken into account. For all bottomfish closed areas, the average length dimension, estimated as the square root of the area, is 9.2 km (interquartile range 7.3 – 13.0 km).

Movements over waters greater than 400 m deep

The southern pinnacle is separated from the other features in the study by waters more than 400 m deep. All other features in the study, Niihau, the guyot and the northern pinnacle, are connected by areas less than 400 m deep. Fish were not detected at the southern pinnacle, and thus no evidence of deepwater crossings was obtained. No fish were tagged at the southern pinnacle. Clearly the study would have benefitted from tagging at this location, but logistical constraints precluded this.

Conclusions

Deepwater eteline snappers tracked with acoustic telemetry made occasional movements across the boundaries of a fishery closed area. *Etelis coruscans* made intermittent movements across the closed area boundary, whereas *Etelis carbunculus* remained within it. Our preliminary results indicate that *E. coruscans* is more mobile, and *E. carbunculus* more site-attached. The movements of both species were of a scale that suggests the closed area offers protection, with *E. carbunculus* being protected more effectively. Movements beyond the limits of the detection network cannot be recorded so it is not known if the individuals travelled outside of the study area. In this study, the widely spaced receiver network meant that the data recovery was low. Future studies should consider the use of acoustic fences or other designs that will increase the capture of data from tagged fish.

Methods

The spatial ecology of commercial bottomfish species were determined by tracking their movements across fishery closed areas and surrounding waters using acoustic telemetry. The study focused on the species of highest management and conservation concern: *Etelis coruscans* (onaga, scarlet snapper), *Etelis carbunculus* (ehu, red snapper), and *Pristipomoides filamentosus* (opakapaka, pink snapper).

Study site

The eastern side of Niihau south of Pueo Point was chosen as a study site due to the presence of several offshore pinnacles and a large guyot, as well as Hawaii State bottomfish restricted fishing area B. This region offers an ideal natural experiment for bottomfish movements, because bottomfish habitat exists on the island slope, as well as on the two pinnacles and guyot, with depths exceeding 400 m between southern pinnacle and the other features. The guyot, the northern pinnacle and the island slope of Niihau are connected by habitat shallower than 400 m.

Acoustic receiver network

In order to quantify the movements of bottomfish a network of acoustic receivers were positioned inside and

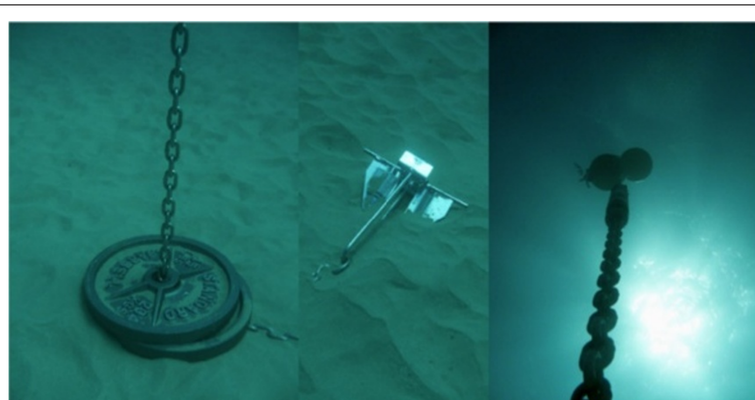

Figure 5 Acoustic listening station comprising Vemco VR2W receiver, Sonardyne LRT releasing mechanism, floats, line, chain, mass anchor, drag anchor.

outside the fishery closed area (Figure 3). The bottomfish habitat is presently defined as a strip along the shelf and slope ranging from 100–400 m [40]. Each receiver station comprised a mass anchor, grapple anchor, chain, shackles, Sonardyne LRT release, rope, Vemco VR2W receiver, deep-rated trawl floats, and flag (Figure 5).

Fishing tagging

Fish were captured using commercial bottomfish gear, comprising a dropper line with four to six circle hooks baited with squid or fish and a 2 kg lead weight at the bottom, deployed with an electric reel. Fish were brought to the surface and placed in a padded cradle with a seawater hose in the mouth. The swim bladder of swollen fish was vented with a syringe and if the stomach was everted it was gently pushed in with a smooth rod (following the release of pressure from the swim bladder). An incision was made with a surgical scalpel and a transmitter inserted into the peritoneal cavity. The incision was closed using medical grade sterile suture. All tags and instruments were soaked in povidone-iodine solution prior to surgery. Transmitters were Vemco V13 coded transmitters with 180-second delay and 1.5 year life. Following surgery the fish were released using a weighted device attached to the fishing line that rapidly returned them to depth [41], provided by the Pacific Islands Fishery Group. Research conducted on rockfishes showed enhanced survival for individuals receiving assisted recompression [21].

Analysis

Each tag has an individual code, such that the movements of a fish from one receiver to another receiver can be determined. Receivers were downloaded to Vemco VUE database software then exported to a comma separated value file for import into MatLab. Track duration was the length of time between the tagging event and the last detection on the network. Since receivers were placed more than their expected detection radius from the closed area boundaries, detections can be interpreted as inside (stations B, F, G and H) or outside (stations A, C, D, E and I) of the closed area. Movements across closed area boundaries were counted as either departures (in-out) or enterings (out-in). Detections by stations B, F, G and H were counted as residency within, while detections by stations A, C, D, E and I were counted as residency outside of the closed area. A single movement was defined as a detection at one receiver, followed by a detection at a different receiver, and the time duration between the two detections varied. The distance of each movement was calculated as a geodesic on an ellipsoid using Vincenty's algorithm [42]. The median movement distance for a fish was the median of each of its single movements.

To avoid pseudoreplication, the average value for each individual was calculated before calculating the average for each species. Data were not normally distributed so the median was used as a measure of center and the Mann–Whitney test to compare between species.

To account for differences in track duration and detection frequency, detection, movement and residency values were normalized by the number of days each fish was detected on the network.

Competing interests

The author declared that he has no competing interests.

Authors' contributions

KCW conducted all parts of the study. All authors read and approved the final manuscript.

Acknowledgements

Funding for this project was provided by the NOAA Pacific Islands Regional Office under award NA05OAR430118. Seed funding was provided by Hawaii Sea Grant UNIHI-SEAGRANT-JC-06-42. Salary support for KW was provided by the Pelagic Fisheries Research Program under Cooperative Agreements NA17RJ1230 and NA09OAR4320075 between the Joint Institute for Marine and Atmospheric Research (JIMAR) and the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subdivisions. Greg Holzman provided expertise and advice based on many years of fishing, and allowed the author to work from his vessel. Thanks to Al Everson, Scott Bloom, Tia Brown, Jason Leonard, Dodie Lau, Johnoel Ancheta, Chris Kelley, Jeff Drazen, Chris Demarke, Bo Alexander, Griff Jones, Jeff Muir, Bonnie Rogers, Clay Tam and the Pacific Islands Fishery Group, Rich Pawlowicz and 'm_map'. Bathymetric data were provided by the Hawaii Undersea Research Lab and the Hawaii Mapping Research Group. This research was conducted under permit from the State of Hawaii Department of Land and Natural Resources, according to a protocol approved by the University of Hawaii at Manoa Institutional Animal Care and Use Committee.

Received: 26 March 2013 Accepted: 12 September 2013
Published: 1 November 2013

References

1. Kaunda-Arara B, Rose GA: Long-distance movements of coral reef fishes. *Coral Reefs* 2004, **23**:410–412.
2. Freiwald J: Movement of adult temperate reef fishes off the west coast of North America. *Can J Fish Aquat Sci* 2012, **69**:1362–1374.
3. Kramer DL, Chapman MR: Implications of fish home range size and relocation for marine reserve function. *Environ Biol Fishes* 1999, **55**:65–79.
4. Costa DP, Breed GA, Robinson PW: New insights into pelagic migrations: implications for ecology and conservation. *Annu Rev Ecol Evol Syst* 2012, **43**:73–96.
5. Weng K, Block B: Diel vertical migration of the bigeye thresher shark (*Alopias superciliosus*), a species possessing orbital *retia mirabilia*. *Fish Bull* 2004, **102**:221–229.
6. Weng KC, Castilho PC, Morrissette JM, Landiera-Fernandez A, Holts DB, Schallert RJ, Goldman KJ, Block BA: Satellite tagging and cardiac physiology reveal niche expansion in salmon sharks. *Science* 2005, **310**:104–106.
7. Teo SLH, Boustany A, Dewar H, Stokesbury MJW, Weng KC, Beemer S, Seitz AC, Farwell CJ, Prince ED, Block BA: Annual migrations, diving behavior, and thermal biology of Atlantic bluefin tuna, *Thunnus thynnus*, on their Gulf of Mexico breeding grounds. *Mar Biol* 2007, 151:1–18.
8. Starr RM, Heine JN, Johnson KA: Techniques for tagging and tracking deepwater rockfishes. *N Am J Fish Manag* 2000, **20**:597–609.
9. Lowe CG, Anthony KM, Jarvis ET, Bellquist LF, Love MS: Site fidelity and movement patterns of groundfish associated with offshore petroleum platforms in the Santa Barbara channel. *Mar Coast Fish* 2009, 1:71–89.
10. Afonso P, Graca G, Berke G, Fontes J: First observations on seamount habitat use of blackspot seabream (Pagellus bogaraveo) using acoustic telemetry. *J Exp Mar Biol Ecol* 2012, **436**:1–10.

11. Mitamura H, Uchida K, Miyamoto Y, Arai N, Kakihara T, Yokota T, Okuyama J, Kawabata Y, Yasuda T: **Preliminary study on homing, site fidelity, and diel movement of black rockfish Sebastes inermis measured by acoustic telemetry.** *Fish Sci* 2009, **75:**1133–1140.
12. Reynolds BF, Powers SP, Bishop MA: **Application of acoustic telemetry to assess residency and movements of rockfish and lingcod at created and natural habitats in Prince William sound.** *PLoS One* 2010, **5**(8):e12130. doi:10.1371/journal.pone.0012130.
13. Cailliet GM, Andrews AH, Burton EJ, Watters DL, Kline DE, Ferry-Graham LA: **Age determination and validation studies of marine fishes: do deep-dwellers live longer?** *Exp Gerontol* 2001, **36:**739–764.
14. Anonymous: *Hawaii seafood buyers guide.* Honolulu, HI: State of Hawaii: Department of Business, Economic Development and Tourism; 1995.
15. Anonymous: *Managing marine fisheries of the US Pacific Islands - past, present and future.* Honolulu, HI: Western Pacific Regional Fishery Management Council; 2003.
16. Anonymous: *Hawaii Administrative Rules, Title 13, Subtitle 4 Fisheries. Honolulu, Hawaii, USA: State of Hawaii, Department of Land and Natural Resources;* 2007.
17. Moffitt RB, Kobayashi DR, DiNardo GT: *Status of the Hawaiian bottomfish stocks, 2004. Administrative report H-06-01.* Honolulu, HI: NOAA; 2006.
18. Friedlander AM, Brown EK, Monaco ME: **Coupling ecology and GIS to evaluate efficacy of marine protected areas in Hawaii.** *Ecol Appl* 2007, **17:**715–730.
19. Sale PF, Cowen RK, Danilowicz BS, Jones GP, Kritzer JP, Lindeman KC, Planes S, Polunin NVC, Russ GR, Sadovy YJ, Steneck RS: **Critical science gaps impede use of no-take fishery reserves.** *Trends Ecol Evol* 2005, **20:**74–80.
20. Puglise K, Kelty R: *NOAA Coral reef ecosystem research plan for fiscal years 2007 to 2011. NOAA technical memorandum CRCP 1.* Silver Spring, MD: National Oceanic and Atmospheric Administration; 2007.
21. Jarvis E, Lowe C: **The effects of barotrauma on the catch-and release survival of southern California nearshore and shelf rockfish (Scorpaenidae, Sebastes spp.).** *Can J Fish Aquat Sci* 2008, **65:**1286–1296.
22. Rogers BL, Lowe CG, Fernandez-Juricic E, Frank LR: **Utilizing magnetic resonance imaging (MRI) to assess the effects of angling-induced barotrauma on rockfish (Sebastes).** *Can J Fish Aquat Sci* 2008, **65:**1245–1249.
23. Rogers BL, Lowe CG, Fernandez-Juricic E: **Recovery of visual performance in rosy rockfish (Sebastes rosaceus) following exophthalmia resulting from barotrauma.** *Fish Res* 2011, **112:**1–7.
24. Winger PD, McCallum BR, Walsh SJ, Brown JA: **Taking the bait: in situ voluntary ingestion of acoustic transmitters by Atlantic cod (Gadus morhua).** *Hydrobiologia* 2002, **483:**287–292.
25. Moffitt R, Parrish F: **Habitat and life history of juvenile Hawaiian pink snapper, *Pristipomoides filamentosus*.** *Pac Sci* 1996, **50:**371–381.
26. Ziemann D, Kelley C: *Detection and documentation of bottomfish spillover from the Kahoolawe Island reserve, phase III final report.* Waimanalo, HI: Oceanic Institute; 2008.
27. Goni R, Quetglas A, Renones O: **Spillover of spiny lobsters Palinurus elephas from a marine reserve to an adjoining fishery.** *Mar Ecol Prog Ser* 2006, **308:**207–219.
28. Abesamis RA, Alcala AC, Russ GR: **How much does the fishery at Apo Island benefit from spillover of adult fish from the adjacent marine reserve?** *Fish Bull* 2006, **104:**360–375.
29. Kellner JB, Tetreault I, Gaines SD, Nisbet RM: **Fishing the line near marine reserves in single and multispecies fisheries.** *Ecol Appl* 2007, **17:**1039–1054.
30. Tupper MH: **Spillover of commercially valuable reef fishes from marine protected areas in Guam, Micronesia.** *Fish Bull* 2007, **105:**527–537.
31. Russ GR: **Yet another review of marine reserves as reef fishery management tools**. In *Coral reef fishes: dynamics and diversity in a complex ecosystem.* Edited by Sale PF. San Diego, CA: Academic Press Inc; 2002:421–443.
32. Law R: **Fisheries-induced evolution: present status and future directions.** *Mar Ecol Prog Ser* 2007, **335:**271–277.
33. Rijnsdorp AD: **Fisheries as a large-scale experiment on life-history evolution - disentangling phenotypic and genetic-effects in changes in maturation and reproduction of north-sea plaice, pleuronectes-platessa L.** *Oecologia* 1993, **96:**391–401.
34. Law R: **Fishing, selection, and phenotypic evolution.** *ICES J Mar Sci* 2000, **57:**659–668.
35. Halpern B, Warner RR: **Marine reserves have rapid and lasting effects.** *Ecol Lett* 2002, **5:**361–366.
36. Berkeley SA, Hixon MA, Larson RJ, Love MS: **Fisheries sustainability via protection of age structure and spatial distribution of fish populations.** *Fisheries* 2004, **29:**23–32.
37. Berkeley SA, Chapman C, Sogard SM: **Maternal age as a determinant of larval growth and survival in a marine fish, Sebastes melanops.** *Ecology* 2004, **85:**1258–1264.
38. Anderson C, Hsieh C, Sandin S, Hewitt R, Hollowed A, Beddington J, May R, Sugihara G: **Why fishing magnifies fluctuations in fish abundance.** *Nature (Lond)* 2008, **452:**835–839.
39. Palumbi SR: **The ecology of marine protected areas**. In *Marine Community Ecology.* Edited by Bertness SMG MD, Hixon ME. Sunderland, MA: Sinauer Associates; 2001:509–530.
40. Anonymous: *Draft EIS: Bottomfish and seamount groundfish fisheries of the Western Pacific region: measures to end bottomfish overfishing in the Hawaiian Archipelago.* Honoulu, HI: NOAA & Western Pacific Regional Fishery Management Council; 2006.
41. Theberge S, Parker S: *Release methods for rockfish.* Corvallis, OR: Oregon State University, ORESU-G-05-001: Oregon Sea Grant; 2005.
42. Vincenty T: **Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations.** *Survey review* 1975, **23:**88–93.

doi:10.1186/2050-3385-1-17
Cite this article as: Weng: A pilot study of deepwater fish movement with respect to marine reserves. *Animal Biotelemetry* 2013 **1**:17.