

Research Article

Post-release survival and movements patterns of roosterfish (*Nematistius pectoralis*) off the Central American coastline

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ABSTRACT. Acoustic telemetry was used to assess immediate post-release survival and track the short-term movement patterns of roosterfish *Nematistius pectoralis* between 2008 and 2010. Seven roosterfish (85 to 146 cm fork length, FL) were continuously tracked along the Central American coastline for periods of up to 28 h following capture on recreational fishing tackle. All seven roosterfish were initially captured and spent the duration of the track period proximal to the coastline in waters <100 m of depth. From depth records and horizontal movements, it was determined that all seven roosterfish survived the acute effects of capture. The greatest depth achieved by any of the tracked individuals was 62 m and collectively roosterfish spent over 90% of the track records between the surface and 12 m. For all tracks, fish size showed no effect on maximum or average dive depth and the average day (7 ± 2 m) and night (6 ± 2 m) depths were similar among individuals. Mean water temperature for all tracks was $28 \pm 1^\circ\text{C}$, with the lowest temperature experienced at depth being 23°C . Total horizontal movements from the roosterfish in this study ranged from 14.7 to 42.2 km and averaged 1.5 ± 0.4 km h⁻¹. Data on movements in relation to bathymetry, prey presence and habitat structure are discussed. Collectively, these data provide insight into the immediate post-release disposition and short-term movements of this poorly studied species along the coast of Central America.

Keywords: *Nematistius pectoralis*, roosterfish, Nematistidae, sport fishing, ecology, Central American coast.

Sobrevivencia post-liberación y patrones de desplazamiento del pez gallo (*Nematistius pectoralis*) frente a la costa centroamericana

RESUMEN. Durante el 2008-2010 se utilizó telemetría acústica para determinar los movimientos verticales y horizontales de corto plazo en pejegallo, *Nematistius pectoralis*, y evaluar la sobrevivencia inmediata después de ser capturados. Se siguieron en forma continua los movimientos de siete pejegallos (85 a 146 cm de longitud furcal) en la costa centroamericana por periodos de hasta 28 h después de ser capturados mediante métodos de pesca deportiva. Todos los pejegallo marcados pasaron la totalidad de su tiempo en aguas costeras a menos de 100 m de profundidad. Los datos de profundidad y de movimiento horizontal mostraron que todos los peces sobrevivieron a la captura. La profundidad máxima obtenida por un pez fue de 62 m y conjuntamente todos los individuos pasaron más del 90% de su tiempo entre la superficie y 12 m de profundidad. Los datos de movimientos no mostraron relación entre la longitud y la profundidad máxima o promedio; la profundidad promedio durante el día (7 ± 2 m) y la noche (6 ± 2 m) no fue diferente. La temperatura promedio del agua durante el estudio fue de $28 \pm 1^\circ\text{C}$ y la temperatura mínima fue de 23°C . Los movimientos horizontales totales variaron de 14,7 a 42,2 km, con una velocidad media de $1,5 \pm 0,4$ km h⁻¹. En este trabajo se presenta y discute datos de desplazamientos en relación con la batimetría, presencia o ausencia de presas y estructura del hábitat. Los datos presentados aportan nueva información sobre los efectos de la captura deportiva y los desplazamientos de esta especie poco estudiada en la costa centroamericana.

Palabras clave: *Nematistius pectoralis*, pejegallo, Nematistidae, pesca deportiva, ecología, costa centroamericana.

INTRODUCTION

The roosterfish *Nematistius pectoralis* is a monotypic species of the family Nematistidae that inhabits the neritic waters of the sub-tropical and tropical eastern Pacific (Eschmeyer *et al.*, 1983). Roosterfish can attain sizes in excess of 50 kg and play a dominant role as a pelagic predator in the coastal waters of Mexico and Central America (Everman & Clark, 1928; IGFA, 1991; Niem, 1995). Despite the importance of this species to the trophic ecology of the eastern Pacific, little information exists on the biology, ecology and movement patterns of roosterfish.

Only sparse accounts exist on the movements of roosterfish in the eastern Pacific, with most of the information available coming from observations and catch records. Along the temperate regions of Baja California, Mexico, it has been suggested that this species undergoes seasonal movements triggered by changes in water temperature and that roosterfish are typically restricted to the nearshore waters (Galván-Piña *et al.*, 2003; Rodríguez-Romero *et al.*, 2009). Observational data of roosterfish feeding in the wild suggest that they routinely prey upon schooling fishes along beaches (Hobson, 1968), and gut contents studies along Baja California Sur, Mexico have suggested this predator to be a specialist that primarily preys upon schooling pelagic fishes (Rodríguez-Romero *et al.*, 2009).

Roosterfish are well known for their elongate dorsal fin that can be raised during the pursuit of prey and are regarded as a prized gamefish that supports vast recreational fisheries throughout the eastern Pacific (Everman & Clark, 1928; Sosa-Nishizaki, 1998; Rodríguez-Romero *et al.*, 2009). In Mexico, this species has been reserved primarily for recreational fishing since 1972 (Sosa-Nishizaki, 1998), as it supports lucrative sport operations along Mexico's west coast and the Sea of Cortez. To a lesser extent, roosterfish are also caught in small scale artisanal fishing operations along the Central American coastline; however, this species is not typically the primary target of such fisheries because of their limited market (Linder, 1947; Niem, 1995). The high sport-value of roosterfish, coupled with the low palatability of its dark-red myotomal musculature (Everman & Clark, 1928), likely contribute to the high rates of catch and release observed in recreational fisheries of the eastern Pacific. For catch and release to function as an effective conservation strategy, post-release disposition must be known and survival rates must be high (Muoneke & Childress, 1994; Cooke & Suski, 2005). Although roosterfish are well known for their strength and endurance while hooked on the line (Everman &

Clark, 1928), it is not known how this species tolerates the acute effects of capture.

To begin to understand the effects of capture and post release disposition, this study used acoustic telemetry to assess immediate mortality in roosterfish captured using recreational techniques. A secondary objective of this work was to document the short-term movement patterns of roosterfish and better understand habitat use in this poorly studied species.

MATERIALS AND METHODS

Capture and tagging procedures

Research activities were conducted under the authority of the Ministerio del Ambiente y Energía Resolución N°141-2006-2010-SINAC. Research cruises were performed during the months of January through May (2008-2010) and entailed three to five days of sampling from two vessels (mother ship and tracking skiff). Most of the field sampling activities were performed proximal to areas targeted by the recreational fleet operating out of Golfito, Costa Rica. Tracking typically commenced with the capture of the first roosterfish encountered during each of the research cruises.

All fish were captured by hook and line, using techniques consistent with those used by Costa Rican sportfishing vessels operating in the region (H. Arouz, *pers. comm.*). Briefly, live (10 to 25 cm) threadfin herring *Opisthonema libertate* and big-eye scad *Selar crumenophthalmus* were slow trolled along the coastline at depths from five to 30 m in areas frequented by the local sportfishing fleet. Terminal tackle consisted of 8/0 non-offset circle hooks (Eagle Claw L2004, USA) with 20 kg fluorocarbon leaders tethered to 15 kg monofilament mainline. All roosterfish were landed using a drag pressure of 3 to 4 kg and fight times ranged from 5 to 25 min (Table 1).

Local sport captains were present during the capture and tagging procedure to ensure that handling time was representative of local fishing activities. The duration of the tagging procedure was maintained within a time period typical of a sport-based release. Once alongside the tracking vessel, roosterfish body size and hook location were recorded by the tracking team. To reduce handling stress, fish were not lifted out of the water and the entire tagging procedure was performed in <1 min after reaching the vessel. All roosterfish were tracked between February 2008 and March 2010 from a 7.5 m panga following the protocols described in previous acoustic tracking studies (Carey & Robison, 1981; Holts & Bedford, 1993; Klimley *et al.*, 2002; Sepulveda *et al.*, 2004) (Table 1).

Table 1. Roosterfish (*N. pectoralis*) acoustic track records from the Central American coastline (2008-2010).

Track No.	Date	Location	Tag type	Fork length (cm)	Fight time (min)	Track duration (hrs)	Depth (m) max, mean(±SD)	Track length (m)			Notes
								Day	Night	Total	
1	2/19/08 2/20/08	Matapalo 08°22'08"N, 83°17'13"W	V16-TP	85	19	28	29, 5±7	7,208 12,014 Σ=19,223	19,450	38,673	observed feeding
2	2/21/08	Tigre River 08°24'54"N, 83°23'41"W	V16-TP	90	10	15.5	20, 7±3	11,388	8,029	19,417	recaptured after 14 days
3	3/29/08 3/30/08	Matapalo 08°22'08"N, 83°17'13"W	V16-P	100	15	28.3	34, 6±3	10,691 6,821 Σ=17,513	18,323	35,837	
4	3/31/08 4/01/08	Matapalo 08°22'08"N, 83°17'13"W	V16-P	80	10	25.3	62, 6±4	11,524 6,212 Σ=17,737	20,710	38,447	recaptured after 60 days
5	4/22/09	Coiba Island 07°20'47"N, 81°44'55"W	V16-TP	146	25	12.5	17, 5±2	29,367		29,367	
6	4/24/09	Coiba Island 07°20'39"N, 81°43'15"W	V16-TP	97	5	9.4	32, 8±5	3,286	9,960	13,246	
7	2/23/10 2/24/10	Matapalo 08°22'08"N, 83°17'13"W	V16-P	102	10	23.2	25, 6±5	4,379 9,133 Σ=13,512	11,304	24,816	

Tag specifications

V16-TP (temperature and pressure, TP) or V16-P (pressure, P) acoustic transmitters (Vemco Electronics; Bedford, Nova Scotia) were affixed to the dorsal musculature of each roosterfish similar to methods used by Holland *et al.* (1996). Transmitter attachment included the use of a plastic nylon anchor, aluminum crimps and 50 kg monofilament (Sepulveda *et al.*, 2010). Transmitters had a power output range of 150–162 dB with frequencies that ranged from 34 to 63 kHz with a rated accuracy of $\pm 5\%$ of total scale (204 m) for depth and $\pm 1^\circ\text{C}$ for temperature. Signals were received and decoded by a Vemco VR100 receiver and a VH110 hydrophone affixed to a tiller system that extended 1.25 m below the lowest point of the tracking vessel hull. The directional hydrophone was rotated to determine the relative bearing to the tagged fish during the track. Depth, temperature and geolocation data (latitude and longitude of the tracking vessel) were recorded every one to three seconds by the VR100 system and subsequently downloaded in the laboratory.

Environmental and bathymetric observations

Because accurate maps of the inshore bathymetry are not available for the study region, detailed observations of fish behavior and environmental conditions were continually recorded during the track period. Observations made by the tracking team included characteristics of the seafloor topography, depth, prey abundance and echo-sounder signatures (Hummingbird Industries, Eufaula, AL, USA). Echo sounder targets observed during the track were verified by hook and line using jigging and sabiki methods (Hamano & Nakamura, 2001), and identified to genus and species. The relative density of echo sounder targets was estimated through visual observation by the tracking crew. For transmitters that did not provide temperature data (Table 1), the water column thermal profile was recorded by a Cefas G5 (Cefas Technology Limited, Suffolk, UK) archival depth and temperature logger that was deployed to the sea floor at 120-min intervals throughout the track session.

Data analyses

Time of nautical twilight (*i.e.*, sunrise and sunset) were determined from the United States Naval Observatory database to differentiate between day and night hours. Diurnal movement patterns for each fish were analyzed for differences in average depth between sunrise (15 min before until 45 min after sunrise), daytime (from 45 min after sunrise to 45 min before sunset), sunset (45 min before and 15 min after sunset), and night (from 15 min after sunset to 15 min before sunrise) using an ANOVA with Tukey *post-hoc* (Ng *et al.*, 2007). A two-

sample T-test was used when an individual track included two daylight periods over two consecutive days. The effect of fish size and fight time on the mean depth and horizontal rate of movement (ROM) were evaluated using regression analyses. ROM values were calculated as described by Cartamil *et al.* (2010), while assuming straight-line distances between position recordings at 5 min intervals. Hourly ROMs were plotted against time of day and data were analyzed for diurnal differences using a paired t-test. All statistical tests used $\alpha = 0.05$ and values are presented as mean \pm SE.

The presence of acoustic noise (*i.e.*, wave action, turbulence and sound producing organisms) and interruptions in data transmission resulted in occasional erroneous temperature and depth measurements. Unreliable data points accounted for $\sim 15\%$ of the entire data set and were filtered from the records using an algorithm based on the transmitter maximum and minimum specifications and signal strength. Once identified as an erroneous value the entire record, including geo-positional information, was omitted from the dataset. The criteria for the removal of such data points followed the protocol outlined in Sepulveda *et al.* (2004). Briefly, individual records were removed if the values were not within the transmitter specifications [depth (0 to 204 m) and for those tracks using TP-transmitters; temperature (0.5 to 35°C)]. For the TP transmitters, values were excluded if consecutive temperature data points deviated by more than 2°C s^{-1} from the water column thermal profile (obtained from the independent deployment of an archival data logger). An additional filter was developed to identify outlying values that were three-times higher or lower than the average of the previous 10 consecutive data points. The filtered depth and temperature data were then averaged into 60-s bins and presented in one-min increments. The initial 120 min of track data were omitted from data analyses to reduce biases associated with behavior related to post-release capture stress. To reduce tracking bias associated with course corrections or interruptions in data transmission, position data were pooled into 5-min bins.

Data limitations

Detailed analyses of both depth and temperature were limited by the rated accuracy of the acoustic transmitters used in this study ($\pm 5\%$ of depth scale; $\pm 10\text{m}$), which were at times greater than the average depths experienced throughout the track. Elevated ambient noise levels near the shoreline and reflected acoustic signal transmissions resulted in data gaps and spurious values which further complicated detailed analyses of vertical activity. Acoustic range tests

performed proximal to the tracking sites revealed a relatively low detection range (>150 m) despite transmitter frequencies and environmental conditions (*e.g.*, day or night, surf conditions). The reduced detection range forced the tracking vessel to be within 100 m of the fish for most of the track sessions. Therefore, comprehensive analyses of horizontal behaviors (*i.e.*, linearity and tortuosity) were not feasible given the repeated need to maneuver and reposition the tracking vessel around navigational hazards (*i.e.*, submerged rocks, high surf). Collectively, these factors reduced the strength of the dataset for detailed assessments of fine-scale habitat use.

RESULTS

Survivorship

Seven individuals ranging in size from 85 to 146 cm (~6 to 30 kg), were acoustically tracked for periods from 9.4 to 28.3 h (Table 1). Based on the track records, all roosterfish survived the acute effects of capture and displayed relatively similar movement patterns (described below), with sinuous or meandering movements (*i.e.*, confined looping within a specific area) beginning within 3 h of release (Figs. 1-3). Longer-term survival was validated by the subsequent recapture of two tagged individuals (roosterfish #2 and #4, Table 1) by local sport fishers 14 and 60 days post-release, respectively.

Post-capture behavior

Tracks typically commenced with fish sounding to depths near the sea floor (verified by the onboard echo sounder) and a rapid departure from the immediate capture area. Depth and horizontal ROM values remained above mean levels throughout the initial 2 h track period. Following this initial period, tracked individuals typically returned to shallower water that was similar in depth to the original capture site. After approximately 4 h, all tracked fish then began to display a noticeable change in behavior, which was identified in both the horizontal and vertical movement records. Specifically, the horizontal movements began to entail looping or sinuous activity and the vertical behaviors began to include oscillations that spanned the entire water column. The vertical movements were primarily centered on depths that corresponded with the greatest echo sounder target densities (*e.g.*, schools of threadfin herring).

For all seven individuals, prolonged periods (3 to 9 h) of reduced vertical movements (*i.e.*, quiescence) occurred over the course of the track. These quiescent periods varied with respect to time of day, tidal cycle

and location. In contrast to the periods of reduced activity, each roosterfish also displayed times of increased vertical activity (Figs. 3-4), which typically coincided with twilight hours, presence of subsurface features, variable coastal terrain (*i.e.*, rock, ledge, river mouth), or an increased abundance of prey species (observed from the echo sounder and confirmed by hook and line).

Depth and temperature distribution

For all tracked roosterfish, there was no significant effect of body size on either maximum ($P = 0.168$, $F = 2.6$, $df = 1,6$) or average ($P = 0.461$, $F = 0.63$, $df = 1,6$) dive depth. Taken together, the average depth occupied by all rooster fish in this study was similar [5.8 ± 0.4 m (sunrise), 6.8 ± 2.6 m (day), 7.1 ± 1.8 m (sunset), and 5.3 ± 0.5 m (night)]. The greatest depth achieved by any individual was 62 m and collectively the fish of this study spent over 90% of the track record between the surface and 12 m. Ambient water temperatures at depth ranged from 23 to 31°C with a mean of $28 \pm 1^\circ\text{C}$.

Horizontal movements

The horizontal distances covered by roosterfish in this study ranged from 14.7 to 42.2 km (Table 1) and the mean rate of horizontal movement for individual fish ranged from 1.20 to 1.76 km h⁻¹. Although mean rates of horizontal movement were similar between individuals, hourly ROM ranged widely from 0.21 to 3.73 km h⁻¹ over the course of tracks. Mean ROM values were significantly greater during the initial 2-h period of the track (Paired t-test, $t = 3.55$, $P = 0.012$), with one individual travelling a maximum distance of 3.73 km within the first h of the track. Horizontal rates of movement were variable throughout all tracks with heightened periods of directed movements along the coastline interspersed with periods of reduced travel. Mean hourly ROM values peaked around sunrise and sunset at >2.0 km h⁻¹ (Fig. 4), however; considerable variability was observed between individuals. There were no apparent relationships between horizontal ROM and fish size or fight time. All roosterfish tracks occurred within 2.6 km of the shoreline, with four individuals spending more than 95% of the tracking period within 1 km of the coast. All tracks along the Osa Peninsula intersected with tracklines of at least one other individual.

Similarities among the tracked individuals included increased activity during the crepuscular hours along with periods of reduced vertical activity while making directed movements at a relatively constant speed between subsurface features (*i.e.*, rocky reef, sand bar). There appeared to be a decrease in directional movements as fish approached and moved in proximity

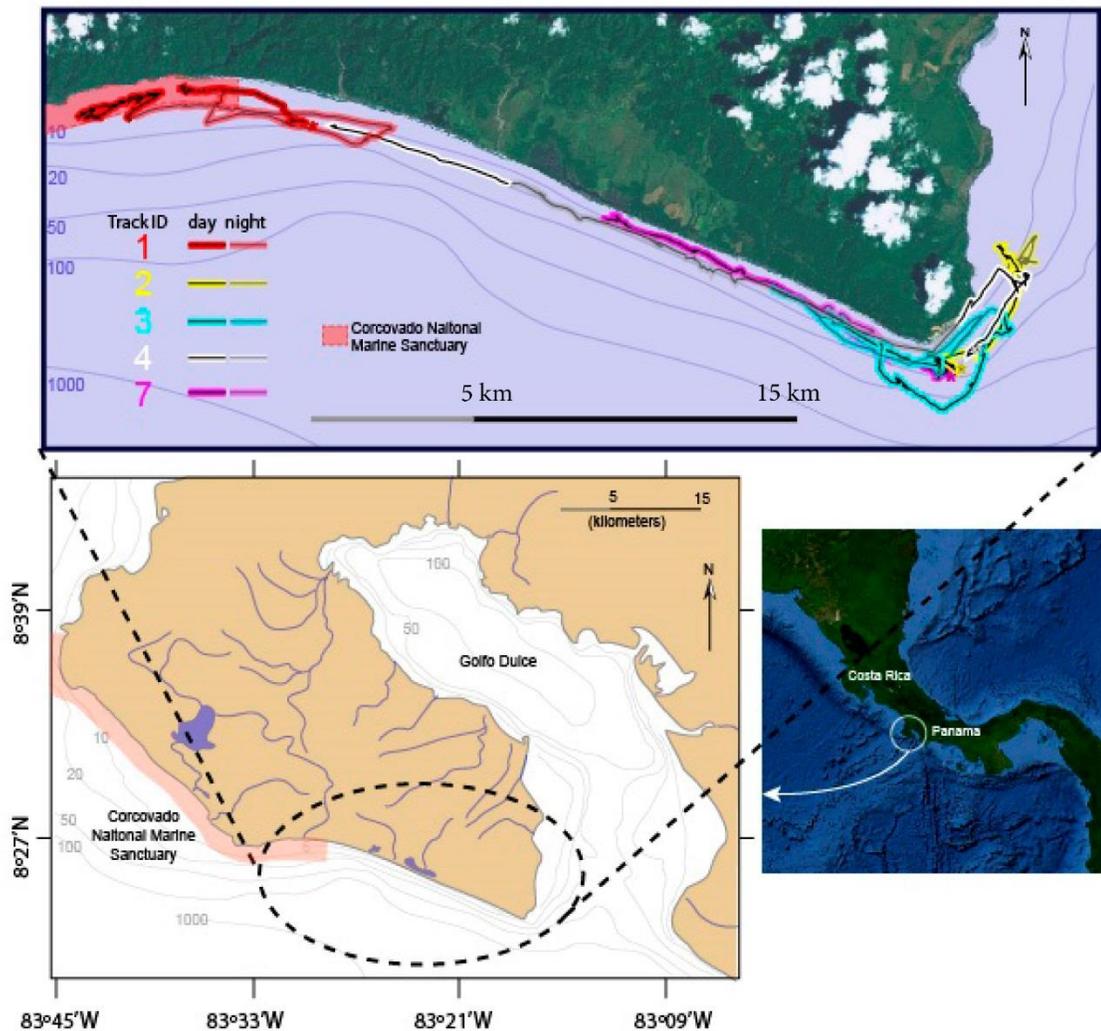


Figure 1. Horizontal track records for roosterfish #1, 2, 3, 4 and 7 tracked along the Central American coastline from 2008 to 2010. Isobath units are in m, an asterisk indicates the origin of the track and shaded lines differentiate between day and night hours.

to areas of high vertical relief (*i.e.*, rocky outcroppings) and in areas with an abundant prey presence (recorded through observations and echo sounder records). Given the similarities among tracked individuals, general trends in the datasets are detailed in two representative tracks (roosterfish #3 and #7) that are discussed below.

Track descriptions

To further describe the post-capture movements observed in this work, two tracks were chosen that contained all of the general behaviors observed in this study (*i.e.*, oscillatory behaviors, periods of quiescence, increased crepuscular movements, and meandering). The tracks for Roosterfish #3 and 7 are displayed in Figure 1 and 3 and discussed in detail.

Roosterfish #3 (110 cm FL), was caught near Matapalo rock ($08^{\circ}22'08''N$, $83^{\circ}17'13''W$) at a depth of 8 m along the Osa Peninsula at 10:20 PST. The total fight time was 15 min and the fish had obvious scars (hooking wounds and monofilament abrasion) indicative of previous capture. Upon tagging, roosterfish #3 immediately moved away from the capture site into deeper water (transitioned from 16 m to 30 m) and moved consistently in a westerly direction for 2 h. Three h later the roosterfish made a direction change towards a nearby rocky reef habitat. Once the roosterfish reached the area of moderate to high rocky relief, repeated oscillations from the surface to the seafloor began to occur. A peak in horizontal rate of movement was observed at sunset with roosterfish #3 moving back to the northeast proximal to the area whe-

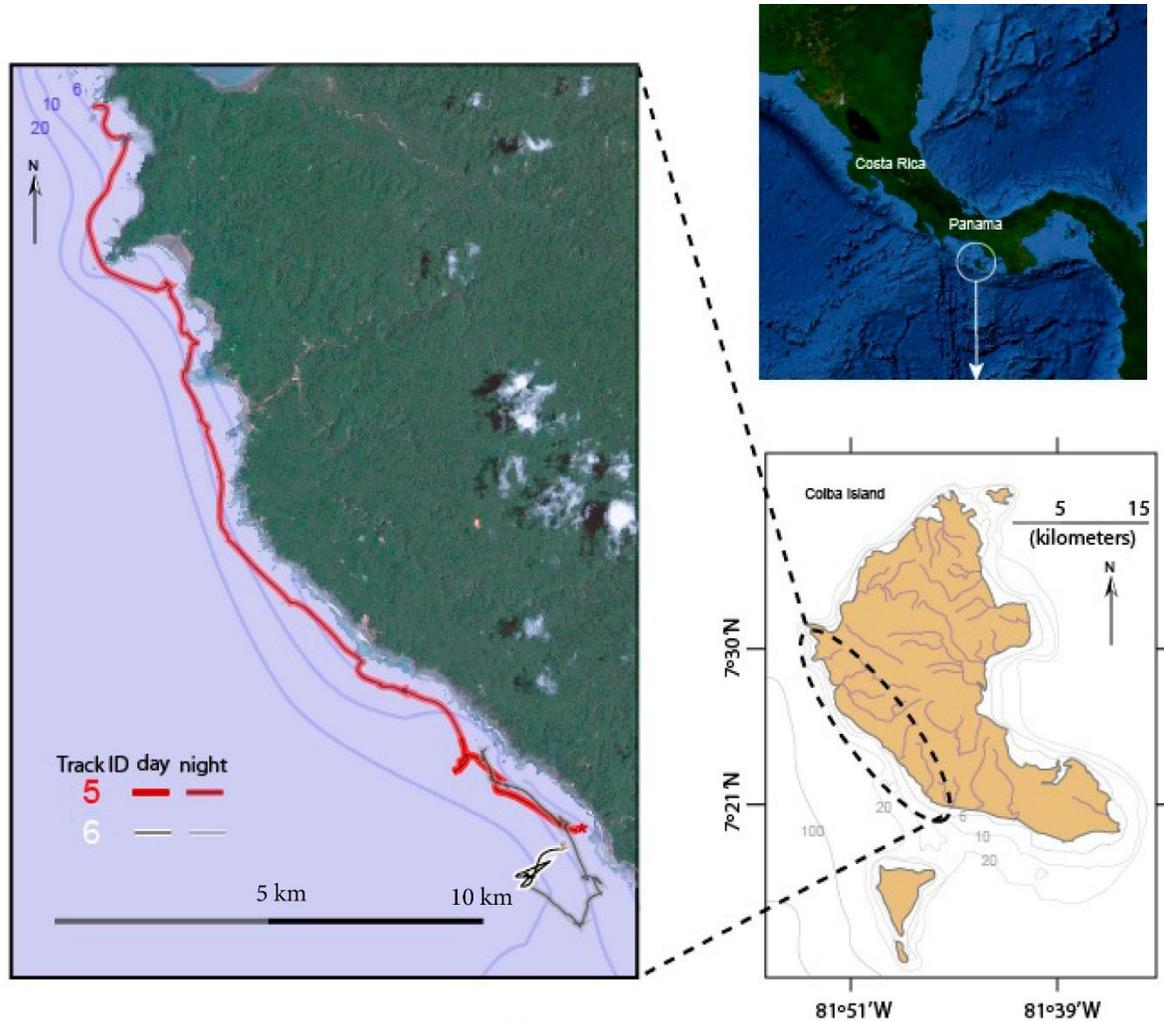


Figure 2. Horizontal track records for roosterfish #5 and 6 tracked along the Central American coastline in 2009. Isobath units are in m, an asterisk indicates the origin of the track and shaded portions differentiate between day and night hours.

re the fish was originally captured. After sunset (20:00 PST), the tracked fish began to exhibit a reduced activity level, moving at a relatively constant depth (~5 m) and speed [approximately 1 body length s^{-1} (BL s^{-1})] for several hours (~7 h). During this period there was also an absence of prey on the echo sounder. During the hour prior to sunrise (approx. 04:30), roosterfish #3 exhibited increased vertical and sinuous movements within a relatively confined area (<100 m) that was proximal to the original capture site (Matapalo Rock). At this popular fishing location several schools of juvenile gafftopsailfin pompano *Trachinotus rhodopus* and juvenile green jack *Caranx caballus* were observed near the surface and on the vessel echo sounder (prey species were confirmed by hook and line sampling). In an attempt to recapture roosterfish #3 and retrieve the sonic transmitter, three additional roosterfish were captured proximal to the tracked fish. The track was

terminated due to equipment complications after 28.3 h.

Roosterfish #7 (102 cm FL) was captured and tagged proximal to Matapalo rock and tracked for 23.2 h (Figs. 1a-3b). The individual was measured and released following a 10 min fight time. During the initial 3 h of the track period the fish made directed movements to the west, parallel to the coastline along the Osa Peninsula. At approximately noon (12:00 PST), fish #7 began to meander, moving back and forth over areas of rocky reef interspersed with periods of directed travel to the west. Observations of consistent prey presence, both visible from the surface and on echo sounder records, were noted during the track of roosterfish #7. At approximately 14:00 PST, the horizontal rate of movement increased and vertical movements decreased for 10 h during which time the fish remained at a relatively constant depth of ~3 m.

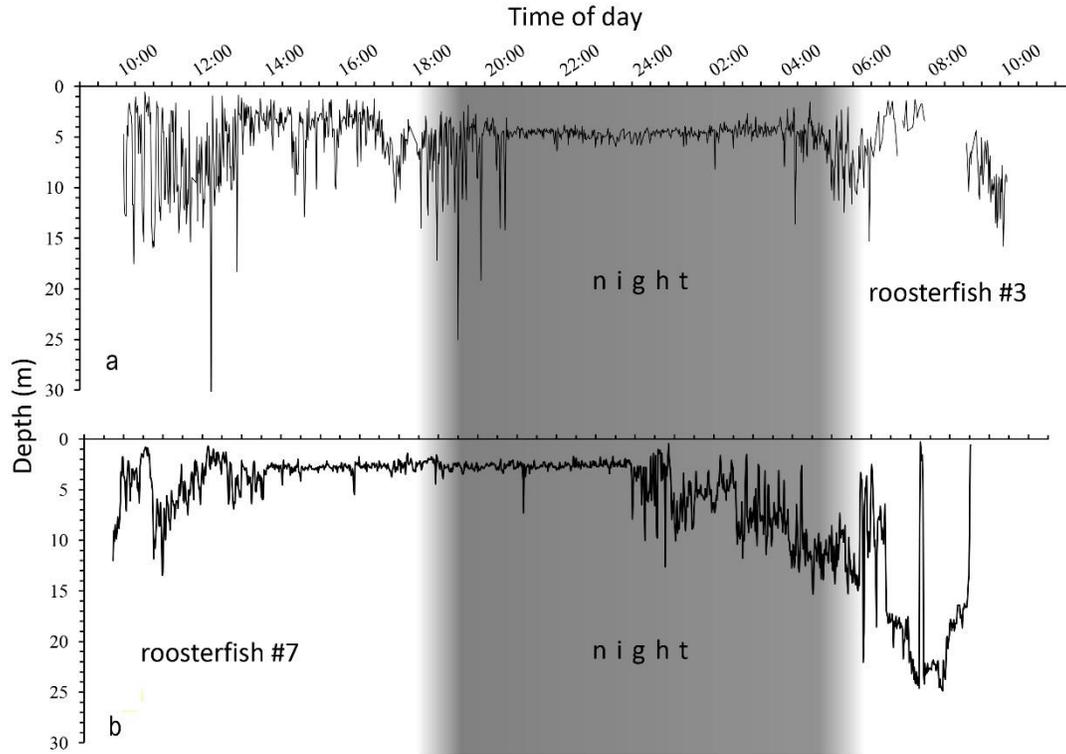


Figure 3. Vertical track records of two representative roosterfish acoustically tracked along the Central American coastline. a) Represents roosterfish #3, b) roosterfish #7. Shaded portions represent night.

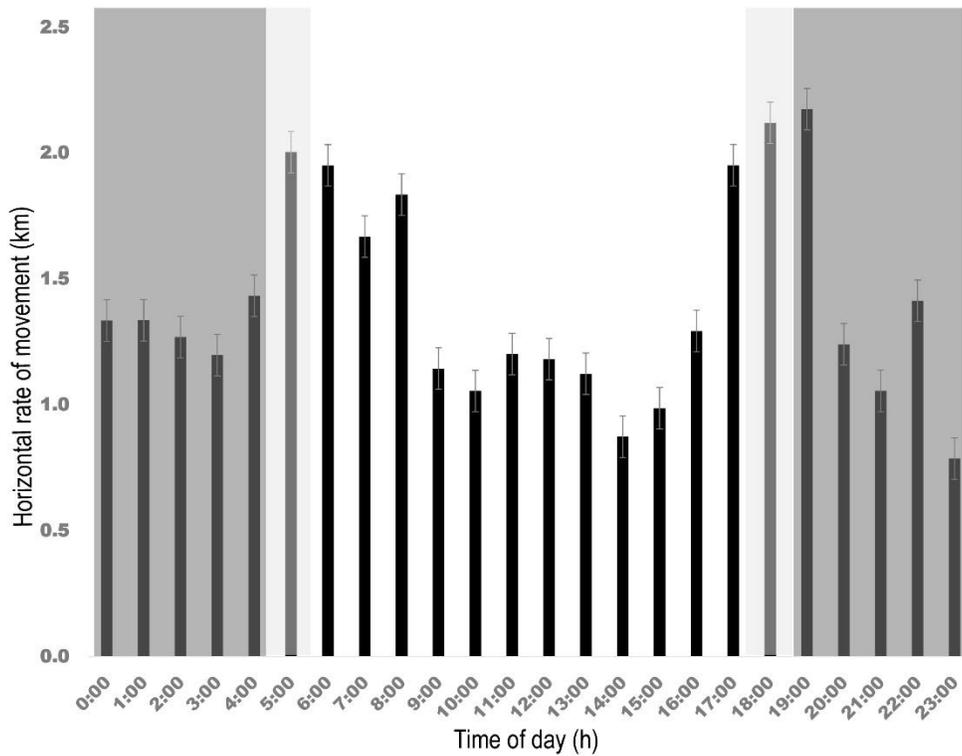


Figure 4. Diel plot of mean (\pm SE) horizontal rates of movement for seven roosterfish tracked off Central America between 2008 and 2010. Dark shaded areas represent night with lighter shaded portions surrounding crepuscular periods and white area is day.

During the period of decreased vertical activity, roosterfish #7 travelled more than 12 km along the coast of the Osa Peninsula. During this time roosterfish #7 appeared to be swimming in the same direction as the surface current (recorded by the tracking team), and remained at a near-constant depth (~3 m). At approximately midnight, roosterfish #7 initiated repeated vertical movements, oscillating from the surface to the seafloor (~14 m). The depth profile throughout the morning of day 2 (06:00 to 09:00 PST) matched closely with the distribution of prey species observed on the echo sounder. Over the course of the track period, roosterfish #7 moved in excess of 28 km from the original release location, with the track terminating proximal to the eastern boundary of the Corcovado National Park (Parque Nacional Corcovado).

Echo sounder verification

Hook and line techniques were used to verify species composition of echo sounder targets observed during the track sessions. The predominant species captured during the verification trials included juvenile pargo manchado *Lutjanus guttatus*, gafftopsail pompano, African pompano *Alectis ciliaris*, threadfin herring, big-eye scad, jack crevalle *Caranx caninus*, green jack, black jack *Caranx lugubris*, and bluefin trevally *Caranx melampygus*.

DISCUSSION

This study provides insights into the post-release survival, movements and habitat preferences of a species that plays a prominent role in nearshore ecosystems in the eastern north Pacific. Based on the track records it is evident that roosterfish can tolerate the acute effects of capture and that short-term survival rates can be high when fish are hooked in the mouth and handled properly. Although additional longer-term studies on survivorship are necessary, these data suggest that current efforts to promote the release of roosterfish are well founded and may serve as an effective management strategy for this species.

Survivorship

Based on the horizontal and vertical movements recorded in this study, all seven roosterfish survived the acute effects of capture for the duration of the track sessions. Although acoustic telemetry is limited with respect to long-term determinations of survivorship, active tracking provides a reliable method to investigate post-release behavior and assess immediate catch and release mortality (Jolley & Irby, 1979; Carey & Scharold, 1990; Holland *et al.*, 1990a; 1993; Pepperell & Davis, 1999; Lowe *et al.*, 2003; Cooke & Philipp,

2004; Sepulveda *et al.*, 2004; Danylchuk *et al.*, 2007). Because post-release mortality rates are greatest in the immediate h following release (Parker *et al.*, 1959; Mason & Hunt, 1967; Warner, 1979; Jolly & Irby, 1979; Aalbers *et al.*, 2004), this study attempted to track individuals for a minimum of 24 h. All three of the tracks that did not meet the 24-h goal, were terminated due to hazardous sea conditions or associated equipment failure (See below *Tracking logistics*).

Although long-term survivorship cannot be confirmed by the techniques employed in this study, several factors are suggestive of the overall health and subsequent disposition of the tracked fish. Roosterfish #1 was observed actively pursuing schools of threadfin herring at the surface with its elongate dorsal fin and red V16 pinger exposed from the water on two separate occasions within 9 h of release. Although this observation does not assure longer-term survival, post-release feeding is a critical step that must occur in order to facilitate recovery (Aalbers *et al.*, 2004; Cooke & Schramm, 2007; Meka & Margraf, 2007). We also observed repeated periods of increased vertical movements (oscillations) during the track sessions, behaviors that have been shown to be associated with foraging activity in several pelagic species (Carey & Lawson, 1973; Pepperell & Davis, 1999; Sepulveda *et al.*, 2004; Cartamil *et al.*, 2010; Nakamura *et al.*, 2011). These behaviors also contrast the unidirectional movements commonly associated with moribund behavior (Moyes *et al.*, 2006; Heberer *et al.*, 2010). Lastly, two of the tagged roosterfish (#2 and #4) were recaptured 14 and 60 days after the tracking experiments had terminated. The recaptured individuals were reported to be in good physical condition, displaying no obvious signs of previous capture other than the presence of an acoustic transmitter. Recaptured individuals provide evidence for longer-term survival and also suggests longer-term site fidelity along the Osa Peninsula.

Capture and handling

All tracked fish were hooked in the mouth using non-offset circle hooks and did not exhibit obvious gill or esophageal trauma. Circle hooks have been shown to reduce hook damage and subsequently lower post-release mortality rates for numerous species (Cooke *et al.*, 2001; Prince *et al.*, 2002; Skomal *et al.*, 2002; Cooke & Suski, 2004; Bartholomew & Bohnsack, 2005). In this study the use of circle hooks resulted in high rates of mouth-hooking in roosterfish, suggesting that circle hooks may provide anglers with a way to enhance post-release survival in catch and release fisheries (Cooke & Suski, 2004; Bartholomew &

Bohnsack, 2005). Similarly, because post-capture handling has been shown to influence survival in several fish species (Muoneke & Childress, 1994; Danylchuck *et al.*, 2007), all tracked fish in this study were quickly measured and tagged alongside the vessel to minimize handling time. Once alongside the vessel, transmitter attachment and release was maintained at <1 min, a time interval that is similar to that associated with typical recreational activities in this region (H. Arouz, *pers. comm.*).

Post-capture recovery

Upon release, roosterfish moved away from the capture site, sounded to the seafloor and displayed reduced vertical activity for 2 to 3 h after release, all responses consistent with short-term capture stress (Cartamil *et al.*, 2010). Similar recovery periods have been reported in other tracking studies of pelagic fishes and sharks (Carey & Scharold, 1990; Holland *et al.*, 1990a; Holts & Bedford, 1993; Pepperell & Davis, 1999). However; factors including water temperature, metabolic scope of the fish, severity of the angling stress as well as hooking injury have all been shown to influence the overall recovery time (Arthur *et al.*, 1992; Milligan, 1996; Bartholomew & Bohnsack, 2005; Danylchuck *et al.*, 2007). Given the short track durations and the lack of pre-capture movement information for this species, the degree to which the capture events influenced the behaviors observed in this study remain unknown. However, Observations of feeding events, increased crepuscular activity, and the return to specific locations all suggest some degree of recovery from the capture event. Future, longer term tagging or behavioral investigations that do not entail capture (*i.e.*, the feeding of transmitters; Sepulveda *et al.*, 2004, Bellquist *et al.*, 2008) are necessary to fully quantify post-capture recovery.

Depth distribution

Among all tracked roosterfish there were no significant differences in the average depth between day and night despite differences in body size, location of track and time of year. The consistent depth distribution observed among the individuals of this study may, in part, be attributed to the shallow coastal habitat (<70 m) occupied by all of the fish of this study (Figs. 1-2). The coastal movements recorded in this work support previous studies that suggest a predominant near-shore distribution for this species (Galván-Piña *et al.*, 2003; Rodríguez-Romero *et al.*, 2009). Although this work was able to document general depth distribution and provide insight into certain behavioral trends, a detailed analysis of vertical habitat use was not practical given the shallow distribution and relatively low accuracy

(±10 m) of the acoustic transmitters used in this study. Further, high levels of ambient noise (*i.e.*, breaking waves, sound producing organisms) within the near-coastal environment provided routine interruptions in signal transmission which also precluded fine-scale analyses. Future, longer-term studies that utilize methods with greater accuracy are necessary to fully assess the depth distribution and movement patterns of this species.

The track records did, however, identify general behaviors that were present in all roosterfish tracks. For example, all individuals displayed periods of quiescence (reduced diving) mostly at night as well as periods of increased vertical activity. Quiescent periods have been shown to occur in the track records of other tropical reef-associated predators such as blue trevally (*Caranx melampygus*) and giant trevally (*Caranx ignobilis*) (Holland *et al.*, 1996, Wetherbee *et al.*, 2004). Unlike the movements of giant trevally and blue trevally, the quiescent periods recorded in this study were frequent both during the day and at night and were most commonly observed when roosterfish transitioned from one habitat feature (*i.e.*, rocky reef, sand bar) to the next. Once a roosterfish located a complex habitat feature, the fish typically exhibited an increase in vertical activity coupled with a more sinuous horizontal path. Given the ecological similarities of roosterfish and the two jack species tracked by Holland *et al.* (1996) and Wetherbee *et al.* (2004), it may be that this is a common strategy used by highly-mobile reef predators that are capable of consuming a wide range of prey species.

In this study, periods of increased vertical activity were observed throughout the records of all tracked roosterfish and were found to occur sporadically throughout the day and mostly during crepuscular periods. The oscillatory behavior typically occurred within relatively confined areas (*i.e.*, 100 to 200 m) of high prey density and proximal to complex topographical features (*i.e.*, reefs and river mouths). Increased vertical activity has been shown to be associated with active foraging in several pelagic fishes (Sepulveda *et al.*, 2004; Bestley *et al.*, 2010; Nakamura *et al.*, 2011), and crepuscular periods have been shown to be consistently important foraging times for many species (Holland *et al.*, 1996). Although this work was not able to verify feeding activity, the observation of tagged roosterfish pursuing prey at the surface in as little as 9 h after release suggests that some of the behaviors recorded in this study are representative of foraging patterns.

Horizontal movements

The roosterfish tracked in this study displayed extensive horizontal movements, with one individual

moving over 42 km in 24 h (Fig. 1). The horizontal movements recorded in this study are much greater than those reported for several other temperate and tropical reef fishes (Holland *et al.*, 1996; Lowe *et al.*, 2003; Wetherbee *et al.*, 2004; Topping *et al.*, 2005; Bellquist *et al.*, 2008) and more similar to those described for pelagic species (Carey & Scharold, 1990; Holland *et al.*, 1990b; Sepulveda *et al.*, 2004; Cartamil *et al.*, 2011). Due to the short duration and relatively unpredictable and extensive nature of the movements reported in this study, calculations of home range and investigations of site fidelity were not feasible. Unlike the movements reported for blue trevally (Holland *et al.*, 1996) the tracked roosterfish commonly moved up to 20 km from the initial release site overnight, often returning to the same structure (*i.e.*, reef) the following day. Because the effects of capture stress cannot be isolated, behavioral patterns are difficult to quantify with short-term datasets (Papastamatiou *et al.*, 2011), prompting the need for future longer term studies.

The predominant horizontal movement patterns observed in this study consisted of periods of directed travel at a relatively consistent speed (0.5 to 1.0 BL s⁻¹) followed by intervals of spatially confined, or sinuous activity. Similar movement patterns, however on a smaller scale, were reported for both blue trevally and giant trevally off Hawaii, which exhibited directed movements followed by periods of reduced horizontal activity within relatively small areas (Holland *et al.*, 1996; Wetherbee *et al.*, 2004). Similar to the work on giant trevally, the roosterfish of this study patrolled the coastline between complex habitat features both during the day and night, with quiescent periods interspersed throughout the track records (Wetherbee *et al.*, 2004). Roosterfish affinity for the shoreline was apparent throughout most tracks, with the vessel trackline commonly encroaching within 50 m of the shore. Factors such as the close proximity of tracked fish to navigational hazards (*i.e.*, high surf, submerged rocks), low detection range of transmitters used, frequent repositioning of the vessel and biases associated with recent capture collectively precluded any detailed analyses of the horizontal behavior.

Echo sounder verification

The sampling of echo sounder targets during the track sessions provided insight into some of the species assemblage that co-occurred in both space and time with the tracked roosterfish of this study. Although some species were likely not sampled due to the selective nature of the jigging methods used in this study (*i.e.*, hook size, line weight, fly type; Hamano & Nakamura, 2001), the size and species composition sampled corresponds directly with the species complex

commonly used as bait for roosterfish and other inshore predators (*i.e.*, jacks, Carangidae) by local sport fishers (H. Arouz, *pers. comm.*). This study also captured and observed other, non-tracked roosterfish, during the track sessions.

Tracking logistics

Although the intention of this study was to track all individuals for at least 24 h, the distances traveled by each roosterfish, extreme weather conditions (*i.e.*, tropical squalls with high winds and heavy rain), high surf, and the close proximity of tracked fish to exposed rocks prevented the team from meeting the temporal goal for three of the seven tracks. Roosterfish #5 and #6 consistently remained proximal to large partially submerged rocks during periods of large swell, therefore these tracks were terminated during the night to avoid complications. The track of roosterfish #2 was prematurely terminated as a result of equipment failure during periods of intense rain and high winds; however, this fish was subsequently recaptured 14 days later by local recreational fishers in approximately the same location. Other complications experienced during the track sessions include the high ambient noise levels from the surfline and other biological sources, both of which contributed to the difficulty of tracking this highly-mobile species.

Management implications

The practice of catch and release has been used as an effective management tool for dozens of species in both the marine and freshwater environments (Muoneke & Childress, 1994; Cooke & Suski, 2005). Although additional long-term assessments of post-release survivorship are necessary, findings from this work suggest that, when handled properly, roosterfish caught using circle hooks can survive the acute effects of capture. For a highly prized and poorly-studied species like roosterfish, promoting catch-and-release may be an appropriate conservation strategy at least until additional biological information (*i.e.*, size at first maturity, age and growth, spawning periodicity) can be collected.

Given the high rates of horizontal movement observed in this study, it is unlikely that most current-day marine protected areas (MPAs) can fully protect the roosterfish resource. However, since at least one of the tracked roosterfish entered the Corcovado National Park (Fig. 1) during the track session, it is apparent that MPA's do offer this species limited protection. However, future studies that address questions related to roosterfish site fidelity and home range are necessary to better understand how MPAs can be more effectively designed to protect this and other highly-mobile

species. Further, longer-term estimates of post-release survivorship may also be valuable in identifying if catch and release techniques are suitable for fisheries to operate within MPAs, as additional fisher opportunities may increase public support for MPAs as well as provide alternative forms of revenue for local ports (Cooke *et al.*, 2006).

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