

NOTE

D.C. Zeller

Tidal current orientation of *Plectropomus leopardus* (Serranidae)

Received: 29 January 2001 / Accepted: 3 January 2002 / Published online: 29 May 2002
© Springer-Verlag 2002

Keywords Behavior · Current orientation · Fisheries · Movement patterns · Reef fish ecology · Ultrasonic telemetry · Space use · Tidal patterns

Introduction

The coral trout *Plectropomus leopardus* (Serranidae) forms the major component of the commercial and recreational line fishery on the Great Barrier Reef (GBR) in Australia (Kailola et al. 1993). Lately, concerns have been expressed regarding rapid increases in fishing effort leading to localized depletion of some target species (Mapstone et al. 1996), and additional spatial or temporal management responses are being considered (Turnbull and Samoily 1997). Furthermore, the growing global interest in the use of marine reserves for fisheries management (e.g., Russ 2002) has resulted in increasing attention being directed at understanding patterns of space use (Samoily 1987, 1997a, 1997b; Davies 1993, 1995; Zeller 1996, 1997, 1998; Zeller and Russ 1998). Samoily (1997a) reported that short-term movements of coral trout, as recorded by visual observations over 15 min, revealed no relationship between behavioral activities (including movements) and tidal state, and concluded that state of tide appeared to have no effect on behavior. In contrast, other observations suggest that coral trout were sighted most often in areas

of observable current flow (e.g., Kingsford 1992). Interestingly, anecdotal information indicates that fishers believe that coral trout either concentrate on up-current ends of reefs ('run-on' side), or have higher catchability in such locations (C. Davies, personal communication). This applies also to small-scale patch reefs. The local distribution of line-fishing effort appears to be influenced by this observation. However, water current related space use patterns of *P. leopardus* have not been documented prior to the present study.

Here, I utilized ultrasonic telemetry as a remote tracking technique to illustrate the patterns of space use of coral trout in relation to observed water currents. The data presented formed part of a project designed to examine large-scale movements in relation to spawning aggregations and marine protected areas (Zeller 1998; Zeller and Russ 1998), and was not specifically designed to measure fine-scale movements in relation to water currents within home ranges. The present findings are therefore rather serendipitous. Thus, no detailed measurements of water current vectors and velocities were undertaken at the time of data collection. Hence, I rely on visual records of water currents obtained during the tracking period from observations of water flow past surface site markers (current direction) and tidal charts (state of tide) to provide basic water current information.

Materials and methods

Ultrasonic tracking of *P. leopardus* was conducted between 1993 and 1995 at Lizard Island, northern Great Barrier Reef, Australia (14°40'S, 145°28'E). Of 39 individuals tracked during six separate tracking sessions spanning 1–3 months each (2024 fish-tracking days; Zeller 1997), 11 specimens had home ranges at locations with recognizable tidal currents (Fig. 1). The remaining individuals had home ranges located at sites with no recognizable current flow, and were thus not considered for the present analysis (but see Zeller 1997).

Specimens were captured on hook and line, and ultrasonic transmitters (Vemco Ltd. and Sonotronics Ltd.) were surgically implanted into the body cavity as described by Zeller (1996, 1999).

D.C. Zeller (✉)
School of Marine Biology and Aquaculture,
James Cook University,
Townsville, Queensland 4811, Australia
E-mail: d.zeller@fisheries.ubc.ca
Tel.: +1-604-8221950
Fax: +1-604-8228934

Present address: D.C. Zeller
Fisheries Centre,
University of British Columbia,
2204 Main Mall, Vancouver,
British Columbia V6T 1Z4, Canada

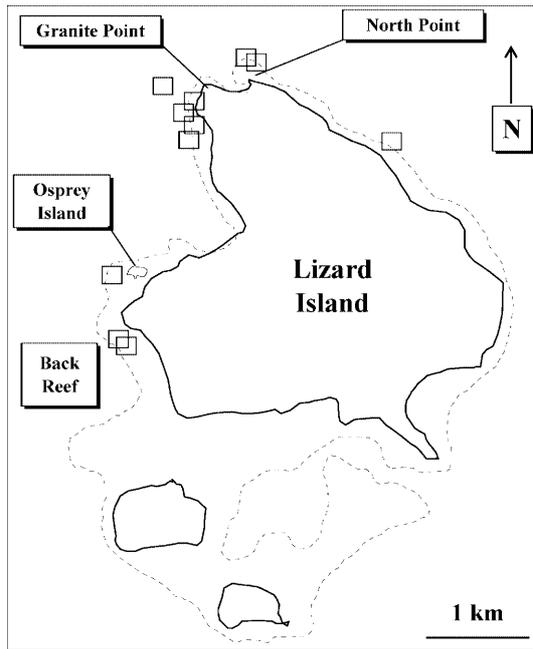


Fig. 1. Locations of the home ranges (squares) of *Plectropomus leopardus* which displayed a distinct pattern of space use in relation to observable water current patterns ($n = 11$). Home ranges of some specimens overlapped (Zeller 1997). Specimens were tracked using ultrasonic telemetry. Prevalent wind direction is from the southeast

Manual tracking was based on the technique described by Holland et al. (1985) and Zeller (1999). Monitoring of specimens commenced immediately after release, but data collected during the first 24 h were not included in the analysis (acclimation period), and movements associated with annual spawning aggregations were also excluded from the data presented here (see Zeller 1998).

Information on directional flow of water currents was obtained from field records of observed water movements past stationary site markers recorded during each position fix of the specimens, and confirmed through personal observations during regular visual checks of tracking specimens on SCUBA. Timings of flood and ebb tides were adjusted for Lizard Island using official tide tables.

Position fixes for each specimen were separated into three tidal states: flood, ebb and neutral tide. All position records ($n = 2188$) were transferred perpendicular onto a linear upstream–downstream tidal axis (see Fig. 2a for example), and the maximum home range dimension for each specimen along the tidal axis was standardized from 0 (direction of approaching ebbing flow) to 1 (direction of approaching flooding flow), to account for differences in home range dimension (Zeller 1997). This resulted in three distributions of standardized positions of fish along the tidal axis, one each for flooding ($n = 1002$), ebbing ($n = 898$) and neutral ($n = 288$) tide stage. The median position for each stage for all specimens combined was compared between tidal stages using a non-parametric median test (Zar 1984).

Results and discussion

The eleven *P. leopardus* tracked at Lizard Island (Fig. 1) displayed distinct patterns of home range use in relation to observable water current patterns. The fish showed a preference for positions located in the upcurrent portions of their respective home ranges as illustrated by the difference between flood and ebb tide median standardized position along the tidal axis ($p \ll 0.001$, χ^2 with Yates' correction

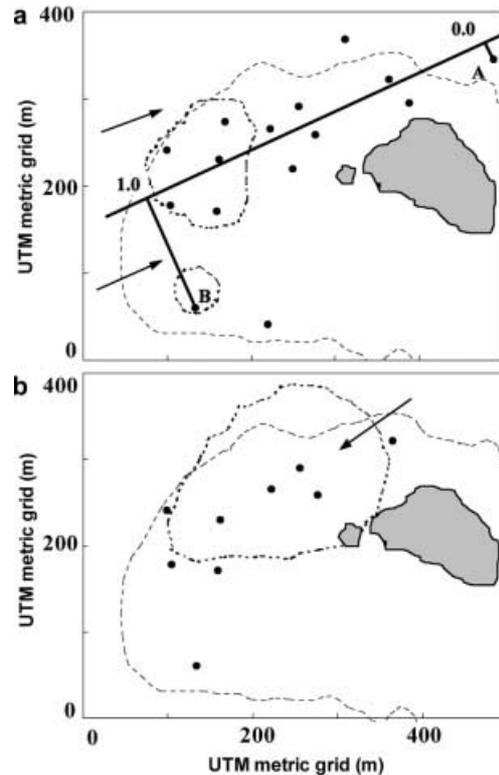
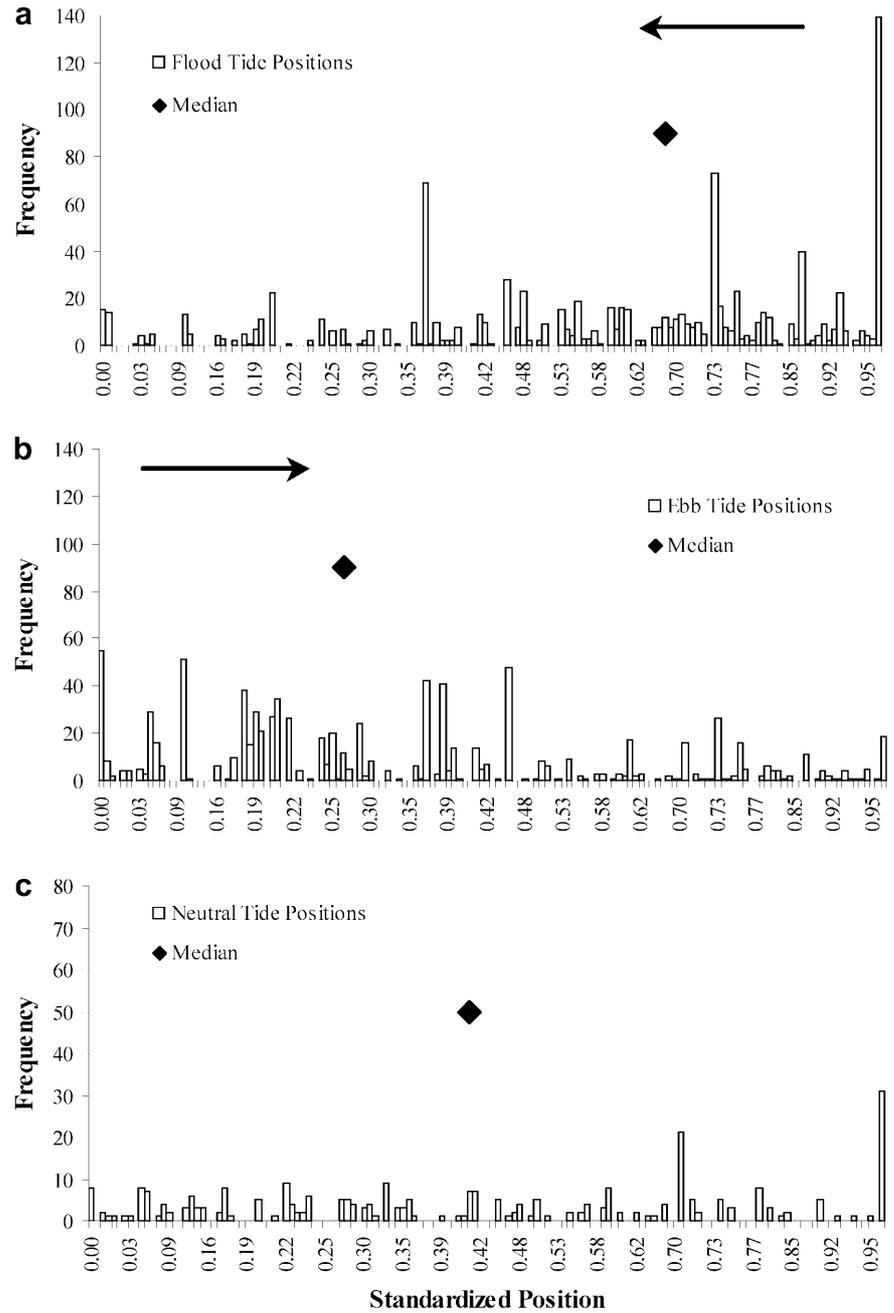


Fig. 2. The different patterns of space use by specimen PL2 in relation to flooding (a) and ebbing (b) tidal currents at a location called Osprey Island. Arrows indicate direction of tidal currents; stippled lines reef crest contour; grey areas land; black circles physical locations at which positions of the specimen were recorded repeatedly by ultrasonic telemetry; dashed line 75% utilization distribution. Indicated also (Fig. 2a) are examples of tidal axis (thick solid line) and the perpendicular transfer of position fixes from physical locations A and B onto tidal axis to form standardized positions 0.0 and 1.0, respectively. Similarly, all positions were transferred from the physical locations to standardized positions on tidal axis for each specimen

correction = 380.5, $df = 1$, Fig. 3a, b). The median position of fish during neutral tide differed also from flooding ($p \ll 0.001$, χ^2 with Yates' correction = 37.56, $df = 1$) and ebbing tide ($p \ll 0.001$, χ^2 with Yates' correction = 26.06, $df = 1$). This preference for intermediate positions during neutral tide (Fig. 3c) appears to reflect fish moving between alternating upcurrent areas.

One individual example may serve to illustrate the general pattern observed between flooding and ebbing tide. This fish inhabited a section of reef near Osprey Island (Fig. 1), which is characterized by directional tidal currents. This fish, tracked from August to October 1993, displayed a distinct current-related pattern of use of its home range (Fig. 2). A strong pattern was observed during incoming tide (flooding flow, Fig. 2a), with six distinct physical locations accounting for 75% of all position records during this tidal stage (sensu Worton 1989; Kie et al. 1996). During outgoing tides (ebbing flow), over 75% of all position records were derived from four physical locations situated on the upcurrent side of its home range, as indicated by the

Fig. 3. Frequency distributions of standardized positions along the tidal axis for *Plectropomus leopardus* ($n = 11$ individuals, 2188 observations) tracked using ultrasonic telemetry, separated by tidal stage. **a** All positions recorded during flooding tides ($n = 1002$ observations); **b** during ebbing tides ($n = 898$ observations); and **c** during neutral tide ($n = 288$ observations). The median standardized position for each tidal stage is indicated. Arrows indicate direction of water flow during each tidal stage



75% utilization distribution contour line in Fig. 2b. Note the tighter clustering of the 75% contour during incoming tide (Fig. 2a), indicating a stronger upcurrent behavior during incoming than outgoing tide.

The present study documents the distinct preference by *P. leopardus* for upcurrent reef locations within their home ranges, and a shift in core area of activity with change in current direction. This lends support to the observation made by commercial fishers that coral trout catches are related to tidal state (Cappo and Brown 1996), and are higher on the ‘run on’ (upcurrent) side of a reef (Davies 1993). This preference for ‘run on’ sides also applies to small-scale reef features, such as individual coral bommies. Thus, the differences in catch per

unit effort between ‘run on’ and ‘run off’ sides of reef structures observed by fishers may, to a large extent, be the result of local movements of fish to upcurrent locations, rather than purely changes in catchability or vulnerability to the fishing gear with the change of tide. Clearly, the effect of bait plume attraction from preferential fishing at upcurrent sides of reefs on the observed catches cannot be ignored.

Given the unplanned nature of the findings presented here (e.g., no dedicated water flow measurements associated with each individual), it was not possible to adequately address the orientation behavior of the 28 individuals with home ranges in areas without recognizable tidal current patterns. Many reef areas around

Lizard Island do not display current patterns readily detectable from a telemetry tracking boat, or have little or no flows. Furthermore, changes in water flow regime with regards to timing of tides vary around the island particularly for low flow areas, and are often influenced by wind direction and strength. Present data, combined with repeated visual observations on SCUBA throughout the tracking periods (Zeller 1997), suggest that if a current is present, *P. leopardus* is likely to orient, but if no current is present, other factors may influence its orientation and behavior. Some previous studies have suggested a link between the behavior of coral trout and tidal currents. For example, Kingsford (1992), using SCUBA observations, recorded *P. leopardus* in larger numbers near reef channels that had stronger currents. Goeden (1978) found feeding activity of coral trout to be highest during flood and high tide. However, the present study was able to uniquely document movements of individual coral trout with regards to changes in water currents.

Studies on orientation in relation to water currents have generally concentrated on planktivorous species (e.g., Hobson 1974; Thresher 1983; Shapiro and Genin 1993). Fitch and Shapiro (1990), summarizing previous studies on the labrid *Thalassoma*, found that in areas with distinct current flow, *T. bifasciatum* was located in groups upcurrent and spent the day feeding on plankton. Bray (1981), in a study on a temperate kelp forest pomacentrid, documented this species undergoing daily foraging movements in relation to water currents. Adult fish invariably aggregated at the upcurrent end of the patch reef studied, and responded quickly to changes in current direction.

Members of the family Pomacentridae (many of which are planktivorous) and other schooling planktivores (e.g., Caesionidae) are among the most abundant prey item in the diet of *P. leopardus* (StJohn 1999). The abundance of planktivores in upcurrent locations of reefs has been observed to come not only from individuals that reside at these locations, but also from daily migrating individuals (Hobson 1991). Both Goeden (1978) and Samoily (1987) recorded that *P. leopardus* followed schools of small schooling fish. It is highly likely that the movements in relation to water currents observed in the present study are an indicator of the feeding behavior and prey selection strategies of *P. leopardus*.

The findings illustrated here have relevance for underwater visual census surveys used to estimate reef fish abundance patterns (e.g., Newman et al. 1997) and population estimates (e.g., Zeller and Russ 2000). Results of individual censuses may be dependent on when, with regards to tidal cycle and local current flow, sampling occurs. For example, replicated censuses in one reef habitat zone (Newman et al. 1997) may be significantly influenced by different tidal flow regimes. Analyses might benefit from factoring out tidal stage, thus potentially reducing data variance. In particular, data from fixed transects used for long-term monitoring (e.g.,

Sweatman et al. 1998) may benefit from such considerations. Clearly, underwater visual census surveys should consider the influence of water currents on the behavior patterns of their target species in survey design, analysis, or interpretation.

Furthermore, the information obtained in the present study may serve as the foundation for modeling of localized targeting behavior of fishers. Similar modeling approaches have been undertaken with respect to targeting behavior in relation to coral trout spawning aggregations (Fulton et al. 1999). Future investigations could address coral trout behavior, bait plume attraction, and patterns of movement in relation to water currents in conjunction with fishers targeting behavior.

Acknowledgments I wish to thank G. Russ for helpful discussions; M. Samoily and an anonymous referee for valuable comments on the manuscript; and numerous volunteers for field assistance. This study was funded by the Australian Research Council and the Lizard Island Research Foundation. Logistic support was provided by the School of Marine Biology and Aquaculture, James Cook University. This is a contribution from the Lizard Island Research Station.

References

- Bray RN (1981) Influence of water currents and zooplankton densities on daily foraging movements of blacksmith, *Chromis punctipinnis*, a planktivorous reef fish. *Fish Bull* 78(4):829–841
- Cappo M, Brown IW (1996) Evaluation of sampling methods for reef fish populations of commercial and recreational interest. CRC Reef Research Centre Tech Rep 6. CRC Reef Research Centre, Townsville, 72 pp
- Davies CR (1993) Inter-reef movement of large reef fishes. Effects of Fishing Project Annu Rep 92/93. Great Barrier Reef Marine Park Authority, Townsville
- Davies CR (1995) Patterns of movement of three species of coral reef fish on the Great Barrier Reef. PhD Diss, James Cook University, Townsville, 203 pp
- Fitch WTS, Shapiro DY (1990) Spatial dispersion and non-migratory spawning in the bluehead wrasse (*Thalassoma bifasciatum*). *Ethology* 85:199–211
- Fulton E, Kault D, Mapstone B, Sheaves M (1999) Spawning season influences on commercial catch rates: computer simulations and *Plectropomus leopardus*, a case in point. *Can J Fish Aquat Sci* 56(6):1096–1108
- Goeden G (1978) A monograph of the coral trout. Res Bull 1. Queensland Fisheries Service, Brisbane, 42 pp
- Hobson ES (1974) Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii. *Fish Bull* 71(4):915–1031
- Hobson ES (1991) Trophic relationships of fishes specialized to feed on zooplankters above coral reefs. In: Sale PF (ed) *The ecology of fishes on coral reefs*. Academic Press, Sydney, pp 69–95
- Holland KN, Brill R, Ferguson S, Chang R, Yost R (1985) A small vessel technique for tracking pelagic fish. *Mar Fish Rev* 47(4):26–32
- Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, McNee A, Grieve C (1993) Australian fisheries resources. Bureau of Natural Resource Sciences, Canberra, 422 pp
- Kie JG, Baldwin JA, Evans CJ (1996) CALHOME: a program for estimating animal home ranges. *Wildl Soc Bull* 24:342–344
- Kingsford MJ (1992) Spatial and temporal variation in predation on reef fishes by coral trout (*Plectropomus leopardus*, Serranidae). *Coral Reefs* 11:193–198
- Mapstone BD, McKinlay JP, Davies CR (1996) A description of commercial reef line fishery logbook data held by the

- Queensland Fisheries Management Authority. Report to the Queensland Fisheries Management Authority from the Co-Operative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef, and the Department of Tropical Environmental Studies and Geography, James Cook University, Queensland
- Newman SJ, Williams DMcB, Russ GR (1997) Patterns of zonation of assemblages of the Lutjanidae, Lethinidae and Serranidae (Epinephelinae) within and among mid-shelf and outer-shelf reefs in the central Great Barrier Reef. *Mar Freshwater Res* 48:119–128
- Russ GR (2002) Yet another review of marine reserves as reef fishery management tools. In: Sale PF (ed) *Coral reef fishes: dynamics and diversity in a complex ecosystem*. Academic Press, San Diego, pp 421–443
- Samoilys MA (1987) Aspects of the behaviour, movements and population density of *Plectropomus leopardus* (Lacepede) (Pisces: Serranidae) at Heron Island reef, southern Great Barrier Reef, Australia. MSc Thesis, University of Queensland, 180 pp
- Samoilys MA (1997a) Movement in a large predatory fish: coral trout, *Plectropomus leopardus* (Pisces: Serranidae), on Heron Island, Australia. *Coral Reefs* 16:151–158
- Samoilys MA (1997b) Periodicity of spawning aggregations of coral trout, *Plectropomus leopardus* (Pisces: Serranidae) on the northern Great Barrier Reef. *Mar Ecol Prog Ser* 160:149–159
- Shapiro DY, Genin A (1993) Feeding whorl induced by strong current in a planktivorous reef fish. *Copeia* 1993(2):542–545
- StJohn J (1999) Ontogenetic changes in the diet of the coral reef grouper *Plectropomus leopardus* (Pisces: Serranidae): patterns in taxa, size and habitat of prey. *Mar Ecol Prog Ser* 180:233–246
- Sweatman H, Bass D, Cheal A, Coleman G, Miller I, Ninio R, Osborne K, Oxley W, Ryan D, Thompson A, Tomkins P (1998) Long-term monitoring of the Great Barrier Reef. Status Rep 3. Australian Institute of Marine Science, Townsville, 303 pp
- Thresher RE (1983) Environmental correlates of the distribution of planktivorous fishes in the One Tree Reef lagoon. *Mar Ecol Prog Ser* 10:137–145
- Turnbull CT, Samoilys MA (1997) Effectiveness of spawning closures in managing the line fishery on the Great Barrier Reef. Report to the Reef Fish Management Advisory Committee of the Queensland Fisheries Management Authority, Queensland Department of Primary Industries, Cairns, 28 pp
- Worton BJ (1989) Kernel methods for estimating the utilization distribution in home range studies. *Ecology* 70:164–168
- Zar JH (1984) *Biostatistical analysis*, 2nd edn. Prentice Hall, Englewood Cliffs, 718 pp
- Zeller DC (1996) Patterns of movement of *Plectropomus leopardus* (Serranidae) in relation to spawning aggregations and marine protected areas, as determined by ultrasonic telemetry. PhD Thesis, James Cook University, Townsville
- Zeller DC (1997) Home range and activity patterns of the coral trout *Plectropomus leopardus* (Serranidae). *Mar Ecol Prog Ser* 154:65–77
- Zeller DC (1998) Spawning aggregations: patterns of movement of the coral trout *Plectropomus leopardus* (Serranidae) as determined by ultrasonic telemetry. *Mar Ecol Prog Ser* 162:253–263
- Zeller DC (1999) Ultrasonic telemetry: its application to coral reef fisheries research. *Fish Bull* 97(4):1058–1065
- Zeller DC, Russ GR (1998) Marine reserves: patterns of adult movement of the coral trout *Plectropomus leopardus* (Serranidae). *Can J Fish Aqua Sci* 55:917–924
- Zeller DC, Russ GR (2000) Population estimates and size structure of *Plectropomus leopardus* (Pisces: Serranidae) in relation to no-fishing zones: mark–release–resighting and underwater visual census. *Mar Freshwater Res* 51:221–228