A quantitative comparison of spearfishing and linefishing on the Great Barrier Reef

A step toward resolving the conflict between recreational fishing sectors

A report to the Queensland Department of Primary Industries and Fisheries

April 2007

Ashley J. Frisch, Ronald Baker, Jean-Paul A. Hobbs, Leo Nankervis

Address for correspondence: Ashley Frisch, School of Marine and Tropical Biology, James Cook University, Townsville, Qld. 4811. E-mail: ashley.frisch@jcu.edu.au

1. EXECUTIVE SUMMARY

Spearfishing and linefishing are the most common forms of recreational fishing on Queensland's coral reefs. Despite the absence of any supportive evidence, it is commonly perceived that spearfishing is more efficient than linefishing with respect to exploiting shared fishery resources – a perception that often leads to strong criticism of the practice of spearfishing. The goals of this study were therefore to directly compare the efficiency of spearfishing and linefishing at exploiting fishery resources and to make this information available for resolving or mitigating the conflict between recreational sectors. To achieve these aims, a structured fishing program was initiated whereby fishing effort for both methods was standardized across time, space and skill level. It was found that (1) the numbers of target fish caught by spearfishers (156) and linefishers (168) were not significantly different, (2) the mean size of target fish caught by spearfishers (1.95 ± 0.1 kg) was significantly larger than the mean size of target fish caught by linefishers (1.27 ± 0.06 kg), and (3) spearfishers retained 43% more biomass of target species than did linefishers (304 *vs* 213 kg, respectively). However, linefishers used approximately 1 kg of bait for every 3 kg of target fish that were captured. Linefishers also caught far more undersized, undesirable or protected fishes (*i.e*. bycatch) and caused far more pollution (*i.e*. lost gear) than did spearfishers. It is concluded that the overall impacts of spearfishing and linefishing on fishery resources are broadly equivalent, and that management regulations should be applied equitably across both recreational sectors. The dissemination of knowledge that spearfishers and linefishers have similar catch rates and impacts on fishery resources is anticipated to reduce conflict among recreational sectors, thereby enhancing enjoyment of recreational fishing in Queensland.

2. INTRODUCTION

The fishery

Linefishing (or angling) and spearfishing are the most popular forms of recreational fishing on Queensland's Great Barrier Reef (GBR) (Hundloe 1985). Linefishing typically involves the use of a single hook on a weighted, nylon line. The hook is usually baited with either self-caught reef fish (*e.g.* fusilier, *Caesio cuning*) or pre-purchased pilchard (*Sardinops* spp.). Spearfishing involves the use of a gas or rubber-propelled spear, as well as associated skin-diving gear such as a mask, snorkel and fins. Because spearfishers choose the fish they shoot, this form of fishing is regarded as highly selective (Mann et al. 1997; Harper et al. 2000). In Queensland, both types of fishing are typically conducted from small (4-6 m) privately-owned boats with 2-3 fishers per boat and one fishing line or spear per fisher (Hundloe 1985; Blamey and Hundloe 1993; Williams and Russ 1994).

Recreational linefishing and spearfishing are enjoyed by thousands of Queensland residents and visitors every year. In the 12 months prior to May 2000, there were approximately 5.8 million recreational fishing events in Queensland, a large proportion of which occurred on the GBR (Henry and Lyle 2003). Recreational fishing is purported to enhance the lives of those who participate in it by providing them with the opportunity to catch food, undertake an outdoor activity, and relax in the natural environment (Blamey and Hundloe 1993; Fedler and Ditton 1994; Henry and Lyle 2003). Not surprisingly, linefishing and spearfishing form the basis of numerous clubs and societies throughout Queensland's coastal communities.

Conflict between sectors

Although linefishers and spearfishers have similar aspirations (Fedler and Ditton 1994; Nakaya 1998), the practice of spearfishing is often strongly criticised (Long 1957; Kieth 1987; Anon. 1992; Eckersley 1997; Mann et al. 1997). This is because of the perception that spearfishing is more efficient than linefishing, which may enable spearfishers to harvest a disproportionate quantity of shared fishery resources (Long 1957; Mann et al. 1997; Harper et al. 2000). In opposition, spearfishers maintain that their sport represents one of the most environmentally-sound fishing methods available, primarily because it has minimal impact on non-target (bycatch) species (Anon. 1992; Eckersley 1997; Smith and Nakaya 2002). Either way, this conflict has effects on the human dimensions of recreational fishing, such as reducing fisher satisfaction (Nakaya 1998). Resolving this issue is therefore important with respect to enhancing the enjoyment of recreational fishing in Queensland.

Current management

At present, spearfishing in Queensland is subject to the same management regulations as linefishing (*e.g.* catch limits, size limits, seasonal closures), except that spearfishing is prohibited from some areas where linefishing is permitted (Anon. 1995, 2003). Aside from these formal regulations, spearfishing is also regulated by the physiological limitations of the diver (*e.g.* dive depth and breath-hold time) as well as the limitations imposed by the marine environment (*e.g.* low visibility, low temperature, sharks). Linefishing, on the other hand, is minimally influenced by environmental factors (Pers. comm., recreational fishers).

In order to reconcile conflicts between different recreational sectors and to provide a sound baseline on which future management decisions can be made, it is important to understand the impacts of spearfishing relative to linefishing. This will enable managers to (1) achieve equitable allocation of fishery resources amongst different users, (2) ensure the sustainability of recreational fishing activities, and (3) provide justification of future management decisions. Currently, data on the relative impacts of recreational spearfishing and linefishing are lacking.

Knowledge gap

It is notoriously difficult to obtain accurate estimates of catch and effort of recreational fishers because Queensland legislation does not require this information to be reported (Higgs 2002). As such, most of the available data on linefishing and all of the available data on spearfishing, come from competitions, questionnaires and personal logbooks (Blamey and Hundloe 1993; Williams and Russ 1994; Nakaya 1998; Higgs 2002). However, these types of data are often biased and unreliable. For example, competition catches are heavily influenced by competition rules (*e.g.* points are awarded for a maximum number of fish for each species; Lincoln-Smith et al. 1989), and thus are unlikely to resemble regular catches in either species composition or catch per unit effort (CPUE). Similarly, studies that utilise questionnaires and logbooks invariably suffer from 'recall bias' (Tarrant and Manfredo 1993; Connolly and Brown 1995). In fact, it has been demonstrated that some fishers over- or under-estimate their fishing effort by as much as 70% (Tarrant and Manfredo 1993; Nakaya 1998). Together, these problems prevent meaningful comparisons of spearfishing and linefishing using available data.

Project objectives

The first goal of this project was to compare the catch characteristics of recreational spearfishing and linefishing. To do this, we engaged a group of recreational spearfishers and linefishers in a structured fishing program. Importantly, both groups of fishers operated concurrently at the same location, thereby avoiding any spatial or temporal biases. The second goal of this project was to use the data to help resolve or mitigate the conflict between recreational fishing sectors and to present user groups with realistic information about their impacts on fishery resources, thereby fostering a greater sense of responsibility with respect to the conduct of recreational fishing activities.

3. MATERIALS AND METHODS

Field surveys

Two teams of fishers, one consisting of two linefishers (one hook and line per person) and the other consisting of two spearfishers (one spear or speargun per person) were instructed to conduct normal recreational fishing activities aboard two small (4-6 m) boats (one team per boat). To standardise fishing effort among teams and over time, linefishers and spearfishers operated concurrently during synchronized 'sessions' which were 1.5 hr in duration. A total of 45 sessions were conducted during twelve one-day 'trips' (3-4 sessions per trip) that were spread across 14 months (May 2005 – July 2006). Consecutive sessions during the same trip were separated by a short recess (0.25-1 hr) and all sessions were completed between 0800-1700 hr. Given that some locations may favour one or other fishing method (Long 1957; Connell and Kingsford 1998), each session was conducted at a different site (*i.e*. an arbitrary area of coral reef that was approximately 1 km^2). Sites were chosen haphazardly and both teams fished the same site at the same time. Within each site, fishers were encouraged to move as often as necessary, but they were not permitted within 100 m of the other boat. Sites were spread across four offshore reefs (Bramble, Britomart, Trunk and Walker Reefs) and three inshore reefs (Palm, Barber and Curacoa Islands), all of which are located in the Townsville region of the Great Barrier Reef Marine Park, north Queensland (Figure 1). For a complete description of the habitat in these locations, as well as estimates of the distribution and abundance of target fish species, see Done (1982) and Newman et al. (1997). To standardise access to reef habitats at each location, fishing was restricted to depths of ≤15 m (this was approximately the maximum working depth of most spearfishers). Since the focus of this study was on reef fishing, all participants were discouraged from targeting pelagic species such as mackerel (F. Scombridae) and trevally (F. Carangidae).

Sampling considerations

It is well recognized that two spearfishers operating from the same boat are unlikely to compete for available fish because they usually swim in different directions. In contrast, two linefishers operating from the same boat are more likely to compete for the same fish at each location. Given that recreational fishers generally operate in groups of 2-3 (Hundloe 1985; Blamey and Hundloe 1993; Williams and Russ 1994), estimates of CPUE by solo linefishers would tend to over-estimate the true CPUE of individuals within a group of recreational linefishers. This study therefore engaged two fishers per boat, thereby mimicking recreational fishing practices as closely as possible.

Most popular food fishes are non-uniformly distributed across small spatial scales (Newman et al. 1997; Connell and Kingsford 1998), a source of variability that may confound potential differences between fishing methods. Thus, it would have been desirable to engage multiple boats per fishing method. This was not possible, however, because only two boats were ever available at any one time. Nonetheless, the use of only one boat per method was considered unlikely to alter the project's outcomes because (1) both teams of fishers were highly mobile and thus capable of moving to a new location (within each site) if local fish abundances were considered unsatisfactory, and (2) any advantage or disadvantage to one or other method was likely to be limited to a single session and each session constituted only a small proportion (2.2%) of total effort.

Given that catch rates are greatly influenced by a fisher's skill (Hundloe 1985; Lincoln-Smith et al, 1989; Cappo and Brown 1996; Mann et al. 1997), we attempted to standardise participants' fishing ability by selecting only those people who (1) regarded themselves as competent recreational fishers, (2) had several years of experience in the relevant fishing method, and (3) had been reef fishing within the last year. We also engaged as many different fishers as could be recruited. Thus, there were nine different fishers per method, and the median number of trips per fisher was two.

Data collection

The identity, size, number and fate of all captured fish were recorded shortly after capture (*n.b*. a fish was defined as any vagile fishery resource, including finfish and crustaceans). Where possible, fish were identified to species level according to Randall et al. (1990) or Jones and Morgan (1994). Some of the less abundant species were identified to the genus or family level only. Body size (±0.5 cm) was recorded as total length (TL) or carapace length (CL) for finfish and crustaceans respectively, and the fate of each animal was categorized into one of the following groups: A = kept to eat; B = kept for bait; C = released in good condition (*i.e*. no significant injury and able to swim without difficulty); D = released or escaped in poor condition (includes any animal that sustained spear-induced injuries); E = discarded dead. Fish that were temporarily hooked on a line but escaped before landing were disregarded. Indirect impacts of fishing were also recorded. This included the amount of pollution (lost gear), the quantity of bait used and the number of times that participating vessels deployed their anchor (*i.e*. the number of 'hangs').

Data analysis

Fish catches were compared in terms of the taxonomic composition, number, length and weight of fish, the latter of which was estimated using length-weight conversion formulae (Kulbicki et al. 2005; Froese and Pauly 2007; Authors' unpublished data). If this information was not available (or the species could not be identified), the conversion formula of a morphometrically-similar, congeneric species was used. Importantly, formula substitutions were considered unlikely to influence overall results because relevant fish were rare and constituted only a small proportion of the total catch.

The numbers of fish retained by each fisher group were compared using a χ^2 goodness-of-fit test, while length-frequency distributions of target species were analysed using a Kolmogorov-Smirnov test (Zar 1999). A Student's *t* test was used to compare mean fish weights, although data were initially transformed ($\log_{10}$ [x + 1]) to overcome heteroscedasticity (Zar 1999). A Student's *t* test was also used to compare mean CPUEs of legal (≥minimum legal size; MLS) fish, both in terms of the number and biomass of captured fish. To calculate CPUE, the number or biomass of fish that were captured during each 'trip' was divided by the amount of time spent fishing, thus giving units of either fish hr^{-1} or kg hr^{-1} (per fisher).

To determine which factor(s) had the greatest influence on catch rates, least-squares classification and regression tree (CART) analysis was used to examine the CPUE of legal fish (excluding bycatch) in relation to trip, fisher and method (De'ath and Fabricius 2000). This type of analysis successively 'splits' the data into increasingly homogenous clusters by minimising the residual sums of squares for each split, analogous to least squares regression (De'ath and Fabricius 2000). In separate analyses, the CPUE of all legal fish and of legal coral trout only, were used as dependant variables, while combinations of trip, fisher and (in all analyses) method were used as explanatory variables. In each case, the 'best' tree models were chosen by bootstrapped cross-validation using both the minimum and minimum + one standard error (1SE) rules (Breiman et al. 1984).

CART analyses were performed using S-PLUS 2000 computer software with the TREEs Plus supplement (Mathsoft, Seattle, U.S.A.). All other statistical analyses were performed using SPSS computer software (SPSS, Chicago, U.S.A). For each test, the relevant assumptions were checked *a priori* and a significant difference was considered to exist if $p < 0.05$ (Zar 1999). All data listed in the text and figures are the (untransformed) arithmetic mean ± 1SE.

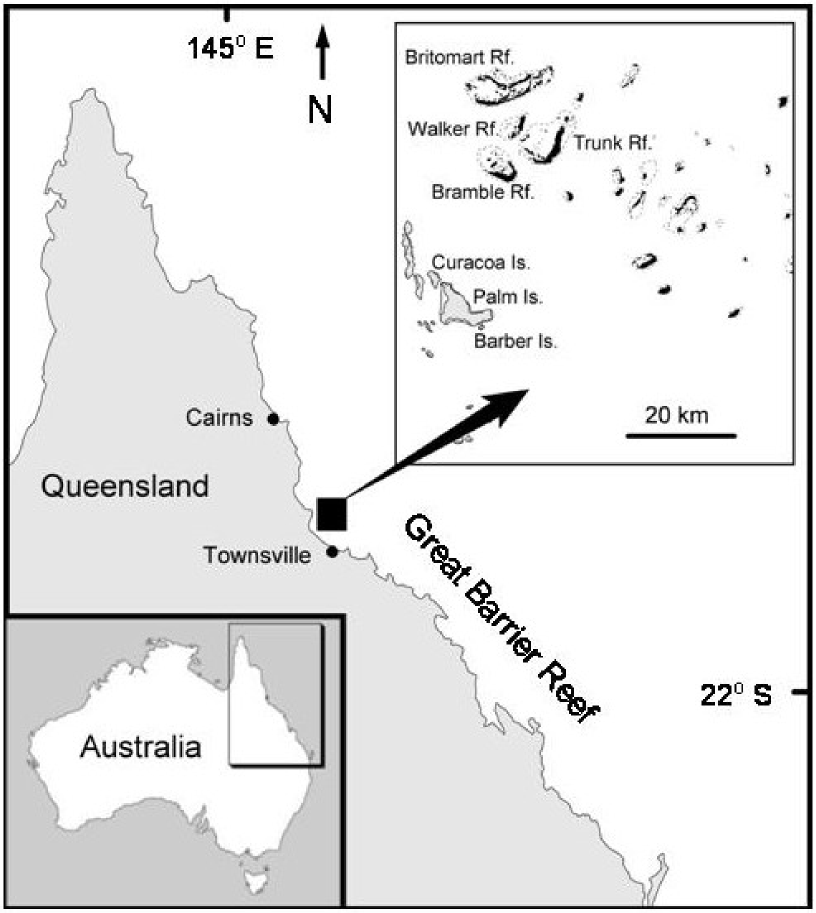

Figure 1. Map of the study area showing the four offshore reefs and three inshore reefs in the Townsville region of the Great Barrier Reef, Australia.

4. RESULTS

Catch composition

A total of 648 fish from ≥45 species were captured during 135 hr of recreational spearfishing and linefishing (Table 1). Spearfishers caught 163 fish belonging to 21 species, while linefishers caught 485 fish belonging to ≥32 species. Most (65%) of the line-caught fish were regarded as bycatch. This included large numbers (140) of blue-spotted rockcod (*Cephalopholis cyanostigma*) as well as two each of barramundi cod (*Cromileptes altivelis*) and red bass (*Lutjanus bohar*), both of which are protected by law (Anon. 2003). Most of the bycatch was subsequently released, although some species were often used as bait (predominantly fusilier, *Caesio cuning*). Excluding bycatch and bait, the numbers of fish retained by spearfishers (156) and linefishers (168) did not differ significantly from a 1:1 ratio ($\chi^2_1 = 0.37$, $p > 0.5$) (Table 2).

For both groups of fishers, the retained portion of the catch was dominated by coral trouts: *Plectropomus leopardus*, *Plectropomus maculatus* and *Plectropomus laevis* (Figure 2). Together, these three species comprised 62% of spearfishers' catch and 73% of linefishers' catch (excluding bycatch). Aside from coral trouts, spearfishers also caught significant quantities of spiny lobsters (F. Palinuridae; 17%), rockcods (F. Serranidae; 6%), parrotfish (F. Scaridae; 6%) and snappers (F. Lutjanidae; 4%). In contrast, linefishers caught (and retained) significant quantities of snappers (14%) and emperors (F. Lethrinidae; 11%), but they did not catch any spiny lobsters, parrotfish or legal-size rockcods (Figure 2).

Size distribution

The mean weight of fish caught by spearfishers (1.95 ± 0.1 kg) was significantly greater than the mean weight of fish caught by linefishers (1.27 ± 0.06 kg, excluding bycatch) ($t_{322} = 7.0$, $p < 0.001$) (Table 2). Similarly, the total biomass of fish retained by spearfishers (304 kg) was greater than the total biomass of fish retained by linefishers (213 kg, excluding bait). With regard to the dominant target species (*Plectropomus* spp.), the mean length of individuals caught by spearfishers (48.9 ± 0.7 cm TL) was significantly greater than the mean length of individuals caught by linefishers (42.9 ± 0.5 cm TL) ($t_{258} = 6.9$, $p < 0.001$)

(Figure 3). Approximately 23% of *Plectropomus* caught by linefishers were below the MLS, while only 3% of *Plectropomus* caught by spearfishers were below the MLS. The length-frequency distributions of *Plectropomus* captured by spearfishers and linefishers were significantly different (Kolmogorov-Smirnov Z = 3.14, p <0.001) (Figure 3). This result did not change even when undersize (<MLS) *Plectropomus* were excluded from the analysis (Kolmogorov-Smirnov Z = 2.38, p <0.001).

Catch per unit effort

The CPUE of spearfishers (1.08 ± 0.12 fish hr^{-1}) was not significantly different to the CPUE of linefishers (1.17 ± 0.15 fish hr^{-1}) in terms of the number of fish captured (excluding bycatch) (t_{46} = 0.44, p = 0.66) (Table 2). In contrast, the CPUE of spearfishers (2.22 ± 0.23 kg hr^{-1}) was significantly greater than the CPUE of linefishers (1.57 ± 0.20 kg hr^{-1}) in terms of the biomass of fish captured (excluding bycatch) (t_{46} = 2.16, p = 0.036). However, CART analyses revealed that CPUE varied more among trips, or among fishers (within trips), than among fishing methods, regardless of which catch component ('all legal fish' or 'legal coral trout only'), dependent variable (fish hr^{-1} or kg hr^{-1}), or combination of explanatory variables (trip, fisher, method) were used in the analyses. In all cases, two-leaf trees were the best models, as indicated by the minimum and minimum + 1SE rules (Table 3).

Bycatch and other impacts

Spearfishers landed and retained 76% of the fish they attempted to catch. The remaining fish either escaped with spear-induced injuries (21%) or were discarded dead (3%) (Figure 4). The latter occurred when a speared fish was found to be <MLS (either because the size of the fish was incorrectly estimated underwater or the MLS was incorrectly remembered by the fisher) or when a speared spiny lobster was found to bear eggs, in which case it was protected by law (Anon. 1995). Linefishers retained 35% of their catch for the purpose of eating. A further 12% were retained for bait. The remaining fish were either released in good condition (47%), released in poor condition (5%), or discarded dead (1%) (Figure 4). Fish in the latter two groups generally suffered from hook-induced injuries and (or) barotrauma. Whilst the exact amount of collateral mortality could not be determined (due to the prospect of delayed effects), it was found that at least 87 reef fish were incidentally

killed or substantially injured as a result of linefishing (including fish kept for bait). In contrast, 51 reef fish were incidentally killed or injured as a result of spearfishing (Figure 4).

During the study, linefishers used 72.2 kg of baitfish. This consisted of 19.4 kg of reef fish (predominantly *Caesio cuning*) and 52.8 kg of pre-purchased pilchards (Table 2). Assuming a mean pilchard weight of 45 g (Authors' unpublished data), the total number of fish used for bait (including reef fish) was approximately 1233. This equates to 2.5 baitfish for each fish that was captured, or 7.3 baitfish for each fish that was kept to eat.

With regard to fishing-associated pollution, spearfishers lost four items of fishing gear, while linefishers lost 96 hooks plus associated lead weights and nylon line (Table 2). Seventy-seven of these hooks were lost when they became 'snagged' on the substrate. The remaining 19 hooks were lost when 'hooked' fish subsequently broke the line. The ultimate fates of these fish were unknown.

Linefishers moved their boat more frequently during each session than did spearfishers. The mean duration of each hang was ~58 min for spearfishers and ~26 min for linefishers. As such, linefishers deployed their anchor more than double the number of times than spearfishers did (Table 2).

Table 1. Summary of linefishers' and spearfishers' catch after 135 hr of structured recreational fishing on the Great Barrier Reef. All fish sizes are listed as cm TL, unless otherwise noted.

Taxon	Target species?[a]	Minimum legal size[b]	Spearfishing		Linefishing	
			Number caught	Size range (mean)	Number caught	Size range (mean)
Serranidae (rockcods and coral trout)						
Cephalopholis boenak	No	38	0	-	5	17-27 (22)
Cephalopholis cyanostigma	No	38	0	-	140	16-34 (25)
Cromileptes altivelis	No	No take	0	-	2	48-50 (49)
Epinephelus caeruleopunctatus	Yes	38	4	39-53 (47)	0	-
Epinephelus coioides	Yes	35	1	51	0	-
Epinephelus fasciatus	No	38	0	-	5	26-29 (28)
Epinephelus fuscoguttatus	Yes	50	5	59-92 (70)	2	42-42 (42)
Epinephelus merra	No	38	0	-	5	25-37 (31)
Epinephelus ongus	No	38	0	-	9	23-33 (29)
Epinephelus polyphekadion	Yes	50	1	47	0	-
Plectropomus laevis	Yes	50	7	45-65 (58)	1	49
Plectropomus leopardus	Yes	38	84	36-61 (48)	154	29-62 (43)
Plectropomus maculatus	Yes	38	9	46-58 (50)	5	33-66 (46)
Lethrinidae (emperors)						
Lethrinus atkinsoni	Yes	25	1	44	10	29-41 (35)
Lethrinus laticaudis	Yes	30	0	-	1	44
Lethrinus lentjan	No	25	0	-	2	30-30 (30)
Lethrinus miniatus	Yes	38	1	53	10	34-53 (46)
Unidentified Lethrinidae	No	25	0	-	9	31-39 (35)
Lutjanidae (snappers)						
Aprion virescens	Yes	38	0	-	1	53
Lutjanus argentimaculatus	Yes	35	3	52-61 (57)	0	-
Lutjanus bohar	No	No take	0	-	2	31-48 (40)
Lutjanus carponotatus	Yes	25	3	31-37 (34)	19	21-37 (31)
Lutjanus fulviflamma	No	25	0	-	9	25-30 (28)
Lutjanus quinquelineatus	No	25	0	-	4	21-23 (22)
Lutjanus russelli	Yes	25	1	41	7	28-35 (33)
Lutjanus sebae	Yes	55	1	46	8	33-50 (40)
Unidentified Lutjanidae	No	25	0	-	2	23-28 (26)

Table 1. (Continued)

Taxon	Target species?[a]	Minimum legal size[b]	Spearfishing Number caught	Spearfishing Size range (mean)	Linefishing Number caught	Linefishing Size range (mean)
Palinuridae (spiny lobsters)						
Panulirus longipes	Yes	-	4	9-10 (9)[c]	0	-
Panulirus penicillatus	Yes	-	2	12-13 (13)[c]	0	-
Panulirus versicolor	Yes	-	22	8-14 (12)[c]	0	-
Miscellaneous						
Caesio cuning	No	-	0	-	49	24-33 (27)
Carangoides spp.	No	-	0	-	6	43-77 (59)
Choerodon venustus	Yes	30	2	38-52 (45)	0	-
Echeneis naucrates	No	-	0	-	1	50
Grammatorcynus bicarinatus	Yes	50	0	-	2	80-81 (81)
Naso unicornis	Yes	25	1	49	0	-
Opistognathus sp.	No	-	0	-	1	36
Plectorhinchus chaetodontoides	Yes	25	1	60	0	-
Scarus microrhinus	Yes	25	9	40-51 (45)	0	-
Synodus sp.	No	-	0	-	1	24
Unidentified Labridae	No	25	0	-	10	21-25 (24)
Nebrius ferrugineus (shark)	No	-	0	-	1	85
Triaenodon obesus (shark)	No	-	0	-	1	90
Octopus sp. (octopus)	No	-	0	-	1	-
Sepia sp. (cuttlefish)	Yes	-	1	-	0	-
Live rock or coral	No	-	0	-	2	-

[a] Target species were those that fishers usually retained to eat.

[b] Many non-target species have a minimum legal size by default (see Anon. 2003)

[c] Carapace length (cm)

Table 2. Catch statistics for recreational spearfishers and linefishers after 135 hr of structured fishing on the Great Barrier Reef. Levels of significance are denoted by asterisks (* p <0.05; ** p <0.001).

	Spearfishing	Linefishing
Diversity of catch (No. of species)	21	≥32[a]
Total catch (No. of fish)	163	485
Legal catch[b] (No. of fish)	156	168
Biomass of legal catch[b] (kg)	304	213
Mean fish weight[b] (kg)	1.95 ± 0.10**	1.27 ± 0.06**
CPUE[b] (fish hr^{-1})	1.08 ± 0.12	1.17 ± 0.15
CPUE[b] (kg hr^{-1})	2.22 ± 0.23*	1.57 ± 0.20*
Bait consumption (kg pilchards)	-	52.8
Bait consumption (kg reef fish)	-	19.4
Pollution (lost gear)	1 knife, 2 spear tips, 1 gun rubber	96 hooks (plus associated lead weights and nylon line)
Number of hangs[c]	70	155

[a] The exact number of species was unknown because some fish were grouped into families or genera.

[b] Excludes organisms that were smaller than the minimum legal size (see Anon. 2003) or regarded as bycatch (*i.e*. not usually retained after capture, unless used for bait).

[c] Refers to the total number of times that participating vessels deployed their anchor.

Table 3. Summary of classification and regression tree (CART) analyses of spearfishers' and linefishers' catch per unit effort (CPUE).

Catch component	Dependant variable	Explanatory variables	Tree size[a]	Split[b]
All legal fish[c]	fish hr^{-1}	method, fisher, trip	2	fisher
	fish hr^{-1}	method, trip	2	trip
	kg hr^{-1}	method, fisher, trip	2	fisher
	kg hr^{-1}	method, trip	2	trip
Legal coral trout only[d]	fish hr^{-1}	method, fisher, trip	2	fisher
	fish hr^{-1}	method, trip	2	trip
	kg hr^{-1}	method, fisher, trip	2	fisher
	kg hr^{-1}	method, trip	2	trip

[a] Indicates the number of homogeneous clusters ('leaves') in the best tree model.

[b] Indicates the explanatory variable that accounted for the greatest amount of variability among clusters.

[c] Excludes organisms that were smaller than the minimum legal size (see Anon. 2003) or regarded as bycatch (*i.e*. not usually retained after capture, unless used for bait).

[d] Includes all *Plectropomus* spp. that were larger than the minimum legal size (see Anon. 2003).

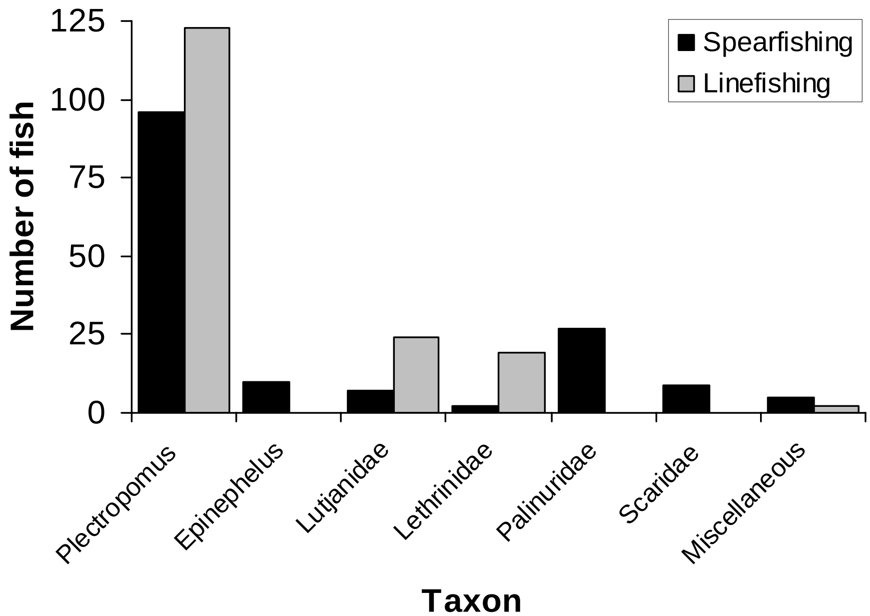

Figure 2. The composition of spearfishers' and linefishers' catch after 135 hr of structured recreational fishing on the Great Barrier Reef. Data exclude organisms that were smaller than the minimum legal size (see Anon. 2003) or regarded as bycatch (*i.e.* not usually retained after capture, unless used for bait).

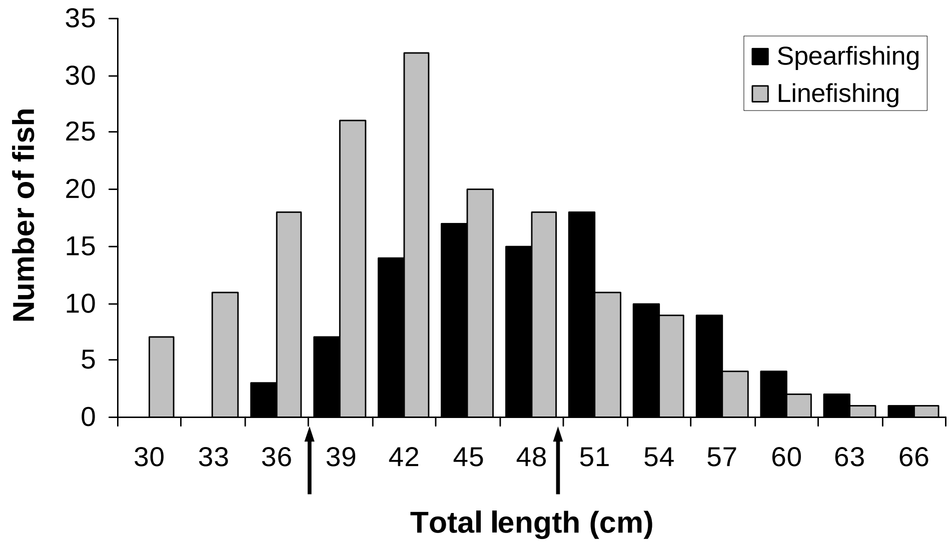

Figure 3. Size distribution of coral trout (*Plectropomus* spp.) that were captured during 135 hr of structured recreational spearfishing and linefishing on the Great Barrier Reef. The *x*-axis labels represent size-class midpoints. Arrows illustrate the minimum legal sizes of *P. leopardus* (38 cm), *P. maculatus* (38 cm) and *P. laevis* (50 cm). Species-specific sample sizes of *P. leopardus*, *P. maculatus* and *P. laevis* were 84, 9 and 7 (respectively) for spearfishing and 154, 5 and 1 (respectively) for linefishing.

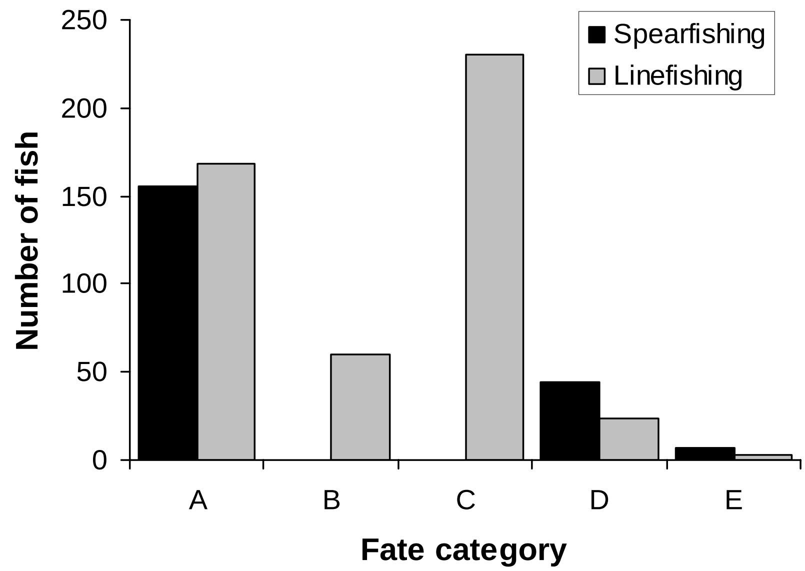

Figure 4. The fate of fish that were captured during 135 hr of structured recreational spearfishing and linefishing on the Great Barrier Reef (A = kept to eat; B = kept for bait; C = released in good condition; D = released or escaped in poor condition; E = discarded dead).

5. DISCUSSION

Much of the conflict between recreational fishing sectors is related to the perception that spearfishing is an overly efficient means of harvesting shared fisheries resources (Long 1957; Mann et al. 1997; Harper et al. 2000). However, the efficiencies of these two fishing methods have never been compared, at least not at the same time, and not without the potential for considerable bias associated with questionnaires and competitions (Blamey and Hundloe 1993; Dalzell 1996; Mann et al. 1997; Nakaya 1998). Results of this study thus provide the empirical data necessary to help resolve or mitigate the conflict between spearfishers and linefishers. The data also provide a sound baseline on which managers can make informed decisions regarding equitable allocation of fishery resources among recreational sectors.

The findings of this study do not support the perception that spearfishing is more efficient at capturing target fish than is linefishing. Both groups of fishers were found to harvest similar numbers of target fish, as well as exploit a similar biomass of fisheries resources (*i.e*. when bait consumption was included; see below). Additionally, because of the considerably larger bycatch, as well as the loss of substantial amounts of fishing gear, it seems that recreational linefishing has the potential to inflict greater incidental impacts on reef ecosystems per unit of effort than does spearfishing.

Catch composition

Although the diversity of food fishes on the GBR is very large (Randall et al. 1990; Grant 1997), it is evident that both spearfishers and linefishers caught and retained only a small number of the available taxa, and that there was a high degree of overlap with respect to the catch composition of both fisher groups (Table 1). These results suggest, firstly, that spearfishers and linefishers have strong preferences for a select few species and secondly, that spearfishers and linefishers compete for the same fish. This overlap is thought to have been the catalyst for past conflicts between recreational sectors (Long 1957; Mann et al. 1997), although conflict can apparently exist even in situations where spearfishers and linefishers target different species (Lincoln-Smith et al. 1989; Nakaya 1998).

Coral trouts (*Plectropomus* spp.) were the principal target species of both fisher groups, a result that reflects the fact that these fishes are highly esteemed, relatively common, and vulnerable to both fishing methods (Heemstra and Randall 1993; Williams 2002; Sadovy et al. 2003). Importantly, spearfishing was not more efficient at capturing coral trout than was linefishing. In fact, linefishers landed more legal-sized coral trout than did spearfishers (Figure 2). The dissemination of such findings among recreational fishers may help to reduce conflict based on the unsubstantiated perceptions about the relative efficiency of spearfishing versus linefishing.

Species other than coral trouts were not generally targeted, but were captured opportunistically according to their respective vulnerabilities to each type of gear. For example, lobsters and parrotfishes were not caught by linefishers because these organisms do not take commonly-used baits. Similarly, few snappers and emperors were caught by spearfishers because these organisms are relatively timid and difficult to approach underwater (Pers. comm., recreational fishers).

Size distribution

It is evident that spearfishers generally caught larger fish than did linefishers (Table 2). This pattern indicates that the two fishing methods have different size selectivities (King 1995; Dalzell 1996), although the difference was probably exaggerated by minimum size limits. Because estimating fish size can be difficult underwater and inadvertently spearing an under-size fish is considered to be wasteful (Pers. comm., recreational fishers), spearfishers tend to avoid fish that appear close the MLS (Figure 3). Linefishers, on the other hand, have the potential to accurately measure a captured fish's size without substantially harming it. Hence, linefishers are more likely than spearfishers to retain smaller fish that approach the MLS.

In ecological terms, it may be beneficial to target larger fish, since it increases the proportion of the population that reproduce before recruitment to the fishery (King 1995). However, it is also undesirable to target very large fish, because they make a disproportionately large contribution to the reproductive output of the population (Sadovy 1996; Birkeland and Dayton 2005). It is therefore pertinent to consider the relative sizes of fish caught by each fisher group. The mean sizes of coral trouts (*Plectropomus* spp.)

caught by spearfishers and linefishers were 48.9 and 42.9 cm TL (respectively). These fishes attain sexual maturity at ~35 cm TL and normally grow to ≥70 cm TL (Heemstra and Randall 1993; Ferreira 1995). The mean size difference of fish caught by spearfishers and linefishers (*i.e.* 6 cm TL) was therefore small relative to the potential size of the fish. As such, the difference between methods with regard to fish size is unlikely to be ecologically significant.

Catch per unit effort

Excluding bycatch and bait, the CPUEs of spearfishers and linefishers were similar with respect to the number of fish captured, but different with respect to the biomass of fish captured, since spearfishers generally caught larger fish than did linefishers (Table 2). However, CART analyses revealed that the variability in CPUE among fishing methods was small in comparison to the variability in CPUE among trips, or among fishers (Table 3). This suggests that the temporal and spatial aspects of fishing effort were more important determinants of CPUE, measured in terms of either the number or biomass of fish, than which fishing method was employed. Whilst it is possible that some of the variability in CPUE was a result of differences in skill among fishers (Hundloe 1985; Lincoln-Smith et al, 1989; Cappo and Brown 1996; Mann et al. 1997) or the spatial heterogeneity of target fish populations (Newman et al. 1997; Connell and Kingsford 1998), it is unlikely that these influences were significant given our criteria for selecting recreational fishers and the structured nature of the sampling design (respectively) (see Section 3, above).

An interesting (but anecdotal) observation was that the CPUE (fish hr^{-1}) of spearfishers was often lower than that of linefishers during sessions when fishing was generally regarded as ‘good’, but that the pattern was reversed during sessions when fishing was generally regarded as ‘bad’. One explanation is that spearfishers experienced ‘gear saturation’ during ‘good’ sessions. In other words, the time required to shoot, retrieve and store a fish may have been limiting for spearfishers when target fish were abundant (*n.b.* some spearfishers individually returned each captured fish to the boat in order to avoid attracting sharks). Another explanation, which is not mutually exclusive, is that spearfishing was more efficient than linefishing when target fish were scarce, or were not concentrated in predictable areas, perhaps because spearfishers actively searched for fish by swimming over a broad area, while linefishers generally selected discrete ‘spots’ in which to deploy their baited hooks.

Studies of other shallow reef fisheries across the Pacific indicate that spearfishers typically catch 0.4-8.5 kg hr^{-1}, while linefishers typically catch 0.5-5.1 kg hr^{-1} (Wright and Richards 1985; Myers 1993; Dalzell et al. 1996; Dalzell 1996). Although those studies engaged artisanal (subsistence) fishers and are thus not directly comparable to this study, it is noteworthy that the CPUEs observed here (2.22 and 1.57 kg hr^{-1} for spearfishers and linefishers, respectively) were within the range of previously reported values. It is also interesting that among those studies, the degree of variation within each fishing method was much greater than the degree of variation between fishing methods, which is congruent with the findings of the present study.

Bycatch and other impacts

In general, spearfishing was found to be much more selective than linefishing, both in terms of species and size. As a result, the total number of undersized, undesirable or protected fishes captured by spearfishers (7) was far less than the number captured by linefishers (257). However, spearfishers’ bycatch was always released dead, while linefishers’ bycatch was generally released in good condition (Figure 4). Furthermore, spearfishers injured an additional 44 fish that escaped before capture (category D, Figure 4). Whilst the fate of these fish is not known, it seems likely that a significant proportion of them subsequently died as a result of their injuries. Similarly, it is likely that a significant proportion of line-caught fish that were released in seemingly good condition (category C, Figure 4) also died, perhaps as a result of post-release predation, stress, delayed barotrauma, or apparently minor mouth injuries (Cooke and Schramm 2007; Rudershausen et al. 2007). The proportion of fish that suffer significant effects or die as a result of fishing-induced injuries contributes to the incidental impacts of spearfishing and linefishing and thus should be integrated into any contemporary management regime. Unfortunately, post-release mortality rates are not available for any of the species encountered here. Estimation of these parameters is therefore considered an important topic for future research.

At least three undersized fish were killed when a spearfisher incorrectly remembered the MLS for a particular species (as opposed to incorrectly estimating the size of a fish immediately prior to shooting it). This suggests that some recreational fishers are inadequately educated with respect to fishing regulations, or that the fishing regulations themselves are too complex to be rapidly recalled. Given that all participants in this study were experienced fishers, the latter explanation seems more likely. Underwater reference cards and (or) simplified regulations may help to resolve this problem.

Bait consumption represents a significant collateral impact of linefishing, because small fishes such as fusiliers often provide important ecosystem functions (Hobson 1991; Graham et al. 2003). In general, linefishers used 1 kg of bait for every 3 kg of fish that were kept to eat. Although it was mentioned earlier that spearfishers exploited a significantly greater biomass of fish compared to linefishers (304 *vs* 213 kg, respectively), the difference was small when the biomass of bait used by linefishers (72.2 kg) was added to their tally. Additionally, baitfish are typically supplied from geographically distant fisheries (Western Australia, California or India in the case of pilchards; Authors' pers. obs.), thus extending the impacts of linefishing to areas that are well beyond local fishing grounds.

Both spearfishers and linefishers were responsible for some degree of pollution. In the case of spearfishers, this consisted of four pieces of lost spearfishing gear (two spear tips, one knife, one gun rubber). However, gear of this nature is unlikely to harm reef organisms when it is lost at sea.. In contrast, the gear lost by linefishers (96 hooks plus associated lead weights and nylon line) may potentially cause collateral mortality of other fish, sharks, turtles and seabirds, either by ingestion of steel hooks or entanglement in nylon line (Matsuoka et al. 2005). Incidentally, if the rate of hooks lost during this project (*i.e.* 1 hook per 1.71 kg of 'legal' coral trouts) is representative of the entire recreational fishery, it is estimated that approximately 190,000 hooks are lost annually on the GBR, since the recreational catch of coral trouts in this region is estimated to be 330,000 kg (Williams 2002).

It is well recognized that coral reefs can be adversely affected by anchor damage, and that the amount of damage is proportional to (among other things) the number of times the anchor is deployed and retrieved (Davis 1977; Dinsdale and Harriott 2004). In the present study, linefishers recorded more than double the number of hangs than spearfishers did, suggesting that linefishers potentially cause a greater amount of anchor damage per unit of fishing effort. This difference is related to the fact that linefishers must retrieve their anchor each time they wish to move to a new area, while spearfishers generally select a single anchorage and thereafter swim between areas.

Conclusions and recommendations

Spearfishers and linefishers were found to catch similar numbers of target fish. They were also found to exploit a similar biomass of fishery resources (*i.e.* when bait consumption was included). Assuming equivalent effort is invested in each fishing method, the findings of this study suggest that the impacts of spearfishing and linefishing are similar, thereby refuting the perception that spearfishing is an overly-efficient method of exploiting shared fishery resources. Across the entire GBR, however, it is likely that spearfishing has a much smaller impact on fish assemblages than does linefishing. Two observations support this hypothesis. Firstly, spearfishing comprises only a very small proportion of the total recreational fishing effort in Queensland (Hundloe 1985; Williams and Russ 1994). In the 12 months prior to May 2000, it was estimated that 13 million hours were spent recreational linefishing, while only 37 thousand hours spent spearfishing, which is a 351 fold difference (Henry and Lyle 2003). Secondly, the depth distributions of target species (see Randall et al. 1990; Heemstra and Randall 1993) extend well beyond the maximum depth achievable by breath-hold divers (~15 m). Hence, the proportion of target fishes available to spearfishers is less than the proportion available to linefishers (Mann et al. 1997).

In conclusion, the results of this study do not support the popular contention that spearfishing is more efficient or more destructive (and thus less sustainable) than linefishing, at least as far as shallow coral reefs are concerned. Instead, our results indicate, firstly, that access to shared fishery resources is equitable, especially with respect to the dominant target species, and secondly, that the overall impacts of each fishing method are broadly equivalent. As such, we advocate that current management regulations are fair and that future management regulations be implemented equitably across both sectors. This will simplify enforcement of fisheries regulations and avoid discrimination of particular fishers in communities where both fishing methods are socially or culturally important.

However, this type of strategy may need to be reviewed once further information is obtained about the incidental impacts of fishing (*e.g.* post-release mortality rates and the effects of lost gear).

It is recommended that the results of this report be made available to recreational spearfishers and linefishers throughout Queensland, perhaps via the Department's own website. The dissemination of knowledge that spearfishers and linefishers have similar catch rates and impacts on fishery resources is anticipated to reduce conflict among recreational sectors, thereby enhancing enjoyment of recreational fishing in Queensland.

6. ACKNOWLEDGEMENTS

The authors are grateful for the numerous recreational fishers who participated in this study. Thanks are also due to the Recreational Fishing Unit (Queensland Department of Primary Industries and Fisheries) for providing financial support. James Cook University provided logistical assistance and John Frisch provided valuable comments on an earlier draft of the manuscript. Katherine Munkres assisted with preparation of the figures. This research was conducted with permission from the Great Barrier Reef Marine Park Authority (Permit no. G05/15590.1).

7. REFERENCES

Anon. (1992) Spearfishing in the Marine Park: Two points of view. Reeflections 27: 14-15.

Anon. (1995) Fisheries regulation. Queensland Government, Brisbane, Australia (available at www.legislation.qld.gov.au).

Anon. (2003) Fisheries management plan. Queensland Government, Brisbane, Australia (available at www.legislation.qld.gov.au).

Birkeland A, Dayton PK (2005) The importance in fishery management of leaving the big ones. *Trends in Ecology and Evolution* 20: 356-358.

Blamey RK, Hundloe TJ (1993) Characteristics of recreational boat fishing in the Great Barrier Reef region. Unpublished report. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Breiman L, Friedman JH, Olshen RA, Stone CG (1984) Classification and regression trees. Wadsworth International Group, California, USA.

Cappo M, Brown IW (1996) Evaluation of sampling methods for reef fish populations of commercial and recreational interest. Unpublished report. CRC Reef Research Centre, Townsville, Australia.

Connell SD, Kingsford MJ (1998) Spatial, temporal and habitat related variation in the abundance of large predatory fish at One Tree Reef, Australia. *Coral Reefs* 17: 49-57.

Connolly NA, Brown TL (1995) Use of angler diaries to examine biases associated with 12-months recall on mail questionnaires. *Transactions of the American Fisheries Society* 124: 413-442.

Cooke SJ, Schramm HL (2007) Catch-and-release science and its application to conservation and management of recreational fisheries. *Fisheries Management and Ecology* 14: 73-79.

Dalzell P (1996) Catch rates, selectivity, and yields of reef fishing. *In* Reef fisheries. NVC Polunin and C Roberts (Eds). Chapman and Hall, London, pp. 161-192.

Dalzell P, Adams TJH, Polunin NVC (1996) Coastal fisheries in the Pacific Islands. *Oceanography and Marine Biology: An Annual Review* 34:395-531.

Davis GE (1977) Anchor damage to a coral reef on the coast of Florida. *Biological Conservation* 11: 29-34.

De'ath G, Fabricius KE (2000) Classification and regression trees: a powerful yet simple technique for ecological analysis. *Ecology* 81: 3178-3192.

Dinsdale EA, Harriott VJ (2004) Assessing anchor damage on coral reefs: a case study in selection of environmental indicators. *Environmental Management* 33: 126-139.

Done TJ (1982) Patterns in the distribution of coral communities across the central Great Barrier Reef. *Coral Reefs* 1: 95-107.

Eckersley Y (1997) War beneath the waves: spearfishing debate surfaces. Geo 19: 18-26.

Fedler AJ, Ditton RB (1994) Understanding angler motivations in fisheries management. *Fisheries* 19: 6-13.

Ferreira BP (1995) Reproduction of the common coral trout *Plectropomus leopardus* (Serranidae: Epinephelinae) from the central and northern Great Barrier Reef. *Bulletin of Marine Science* 56: 653-669.

Froese R, Pauly D (2007) FishBase. International Centre for Living Aquatic Resource Management, Manila (available at www.fishbase.org).

Graham NAJ, Evans RD, Russ GR (2003) The effects of marine reserve protection on the trophic relationships of reef fishes on the Great Barrier Reef. *Environmental Conservation* 30: 200-208.

Grant E (1997) Guide to fishes. E.M. Grant Publishers, Scarborough, Australia.

Harper DE, Bohnsack JK, Lockwood BR (2000) Recreational fisheries in Biscayne National Park, Florida, 1976-1991. *Marine Fisheries Review* 62: 8-26.

Heemstra PC, Randall JE (1993) Groupers of the world: FAO Species Catalogue 16. Food and Agriculture Organization of the United Nations, Rome.

Henry GW, Lyle JM (2003) The national recreational and indigenous fishing survey. Unpublished report. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

Higgs J (2002) Queensland recreational fisheries. *In* Queensland's fisheries resources: current condition and recent trends 1988-2000. LE Williams (Ed.) Department of Primary Industries, Brisbane, Australia, pp. 4-6.

Hobson ES (1991) Trophic relationships of fishes specialized to feed on zooplankters above coral reefs. *In* The ecology of fishes on coral reefs. PF Sale (Ed.). Academic Press, San Diego, pp. 69-95.

Hundloe T (1985) Fisheries of the Great Barrier Reef. Prestige Litho Printing, Brisbane, Australia.

Jones DS, Morgan GJ (1994) A field guide to crustaceans of Australian Waters. Reed, Chatswood, Australia.

Kieth V (1987) Should spearfishing be banned? *Skindiver* 36: 144-145.

King M (1995) Fisheries biology, assessment and management. Blackwell Science, Oxford.

Kulbicki M, Guillemot N, Amand M (2005) A general approach to length-weight relationships for New Caledonian lagoon fishes. *Cybium* 29: 235-252.

Lincoln-Smith MP, Bell JD, Pollard DA, Russell BC (1989) Catch and effort of competition spearfishermen in southeastern Australia. *Fisheries Research* 8: 45-61.

Long EJ (1957) Anglers versus spearmen. *Sea Front* 3: 130-141.

Mann BQ, Scott GM, Mann-Lang JB, Brouwer SL, Lamberth SJ, Sauer WHH, Erasmus C (1997) An evaluation of participation in and management of the South African spearfishery. *South African Journal of Marine Science* 18: 179-193.

Matsuoka T, Nakashima T, Nagasawa N (2005) A review of ghost fishing: scientific approaches to evaluation and solutions. *Fisheries Science* 71: 691-702.

Myers RF (1993) Guam's small-boat-based fisheries. *Marine Fisheries Review* 55: 117-128.

Nakaya S (1998) Understanding behaviour, motivations and attitudes of spearfishers on the Great Barrier Reef through the multidimensional specialisation concept. Unpublished PhD thesis. James Cook University, Townsville, Australia.

Newman SJ, Williams AM, Russ GR (1997) Patterns of zonation of assemblages of the Lutjanidae, Lethrinidae and Serranidae (Epinephelinae) within and among mid-shelf and outer-shelf reefs in the central Great Barrier Reef. *Marine and Freshwater Research* 48: 119-128.

Randall JE, Allen GR, Steene RC (1990) Fishes of the Great Barrier Reef and Coral Sea. Crawford House Press, Bathurst, Australia.

Rudershausen PJ, Buckel JA (2007) Discard composition and release fate in the snapper and grouper commercial hook-and-line fishery in North Carolina, USA. *Fisheries Management and Ecology* 14: 103-113.

Sadovy YJ (1996) Reproduction of reef fishery species. *In* Reef fisheries. NVC Polunin and C Roberts (Eds). Chapman and Hall, London, pp. 15-59.

Sadovy Y, Donaldson TJ, Graham TR, McGilvray F, Muldoon GJ, Phillips MJ, Rimmer MA, Smith A, Yeeting B (2003) While stocks last: the live reef food fish trade. Asian Development Bank, Manila.

Smith A, Nakaya S (2002) Spearfishing - Is it ecologically sustainable? Third World Recreational Fishing Conference, Darwin, Australia, pp. 19-22.

Tarrant MA, Manfredo MJ (1993) Digit preference, recall bias, and non-response bias in self reports of angling participation. *Leisure Sciences* 15: 231-238.

Williams DM, Russ GR (1994) Review of data on fishes of commercial and recreational fishing interest in the Great Barrier Reef. Unpublished report. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Williams LE (2002) Queensland's fisheries resources: current condition and recent trends 1988-2000. Department of Primary Industries, Brisbane, Australia.

Wright A, Richards AH (1985) A multi-species fishery associated with coral reefs in the Tigak Islands, Papua New Guinea. *Asain Marine Biology* 2: 69-84.

Zar JH (1999) Biostatistical Analysis. Prentice-Hall, London.