Received: 7 November, 2012

Innovative and cost-effective approaches for surveying specialised recreational longtail tuna fishers in Australian waters

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Abstract Advances in fishing technologies have increased the efficiency and diversification of recreational fisheries. This poses challenges for surveying specialised or 'hard-to-reach' recreational fishers (e.g. sport fishers) that may take the majority of the recreational catch for some species, such as longtail tuna, but are too rare within the general population to be sampled cost-effectively using existing methods. We trialled two new methods – time-location sampling (TLS) and online diaries – for surveying specialised recreational fishers who target longtail tuna in Australian waters. Results were compared with a concurrent traditional access point survey (APS). Online diaries were inexpensive but unsuitable for collecting representative data due to avidity, volunteerism, and differential recruitment bias. APS yielded high resolution data on catch, effort and size composition but was expensive and ineffective for sampling all components of the fishery. In contrast, TLS conducted at fishing tackle stores was cost-effective for accessing the breadth of fisher types due to the need for all fishers to purchase or to inspect fishing-related products at some point. Given the frequent absence of complete list frames for recreational fisheries, we suggest undertaking multiple TLS surveys to collect catch rate data and to simultaneously estimate population size using capture-recapture approaches in order to estimate the total recreational catch of species of interest.

Keywords

hard-to-reach · rare · sport fishing · game fishing · survey design · longtail tuna

Introduction

Recreational fishing is an important social and sporting activity in many countries worldwide. However, the recreational catch of many species has increased in recent years due to increasing human populations near coasts and waterways, and improved efficacy of fishers owing to improvements in fish searching technologies, fishing tackle, and information exchange (e.g. internet forums) (McPhee et al. 2002, Post et al. 2002, Griffiths et al. 2010). This technology 'creep' has also led to diversification of an already highly segmented recreational fishing sector (Fisher 1997, Lawrence 2005), where some fishers are increasingly specialising in targeting species that were once only available to commercial fisheries (e.g. swordfish in deep oceanic waters). For example, Griffiths and Pepperell (2006) showed recreational fisheries now share 245 commercially-important species across 20 of the 21 Commonwealth fisheries in Australia. In some cases, this has resulted in conflict between commercial and recreational sectors over resource allocation (Bromhead et al. 2004, Goodyear 2007).

Diversification of recreational fisheries poses an increasingly difficult problem for scientists to cost-effectively estimate the recreational catch of some species for inclusion in stock and resource allocation assessments. This is largely due to the difficulty in surveying specialised fishers since they comprise only a small fraction of a larger recreational fishing population that is distributed heterogeneously in space and time, for which a complete list frame of fishers rarely exist. In the United States for example, specialist mackerel sport fishers comprise only 6.3% of saltwater recreational fishers and just 1.6% of an estimated total population of 30 million recreational fishers (U.S. Department of the Interior 2006). The sampling effort required to obtain a random sample of fishers using traditional survey methods is therefore often cost prohibitive and ineffective due to various sampling and non-sampling biases (Teisl and Boyle 1997, Griffiths et al. 2010). Telephone surveys in particular are becoming increasingly ineffective for such large-scale general population surveys due to a marked increase in non-response and refusals (Curtin et al. 2005, Groves 2006). However, simply ignoring such 'hard-to-reach' components can have a significant effect on overall population parameter estimates (Keeter et al. 2006, Odierna and Schmidt 2009), particularly in recreational fisheries as these specialised fishers are likely to contribute significantly to the total fishing effort and catch for some species.

Epidemiologists and social scientists frequently study rare, hidden or hard-to-reach populations (e.g. sex workers, illicit drug users, the homeless) using various cost-effective survey methods. These include methods such as venue-based, targeted, and time-location sampling (TLS), which capitalise on the tendency of their target populations to gather at specific locations and times (Watters and Biernacki 1989, Mackellar et al. 1996, Muhib et al. 2001, Stueve et al. 2001). For example, illicit drug users and sex workers often congregate at night in venues such as needle exchange clinics, 'shooting galleries' and brothels (Magnani et al. 2005). By stratifying sampling in space and time across a random sample of all possible venues in a region of interest – or a 'sampling universe' – a probability sample of individuals can be intercepted, who would not normally be easily identified, intercepted or recruited from within the general population at other times or locations.

Specialised recreational fishers also have a similar tendency to congregate at specific venues such as fishing tackle stores (Pepperell 1994) and trade shows (Lichtkoppler et al. 1993, Arlinghaus and Mehner 2003), and therefore TLS may be a cost-effective survey option. Access point surveys (APS) commonly employed in recreational fishing surveys to intercept fishers at boat launching ramps rely on similar principles as TLS, but they underrepresent land-based fishers and boat-based fishers departing from marinas, moorings or private property (Pollock et al. 1994). In contrast, TLS conducted at tackle stores may obtain a more representative sample from the entire recreational fishing community since most fishers, regardless of their ability, avidity or mode of fishing, need to purchase or inspect fishing-related products at some point.

Online surveys are another cost-effective technique used to study hard-to-reach or stigmatised populations and are being increasingly used in recreational fisheries research (e.g. Arlinghaus and Mehner 2003, Schramm and Hunt 2007). They can be used to inexpensively collect data across large spatial and temporal scales and have the flexibility to record more detailed information than other traditional methods such as telephone surveys, where interview times are often minimised to ensure each respondent completes an entire survey (Hansen 2007). In addition, sampling effort is not usually expended on ineligible subjects, since only eligible individuals will be motivated to participate, thereby increasing sampling efficiency. With increasing use of computers and the internet by members of the general population, online reporting may be an inexpensive and rapid means to collect a large amount of data across large spatial scales for specialised recreational fishers.

The aim of the present study was to compare the efficacy of time-location sampling and online diaries with a traditional access point survey for reaching specialised components of recreational fisheries. The highly specialised recreational fishery targeting longtail tuna (*Thunnus tonggol*) in Australia was used as a case study since this fishery is comprised of boat-based and land-based fishers who are dispersed across thousands of kilometres of coastline, which makes cost-effectively obtaining a representative sample a challenging prospect. The aim of the study was not to attempt to collect information to estimate the total recreational catch of longtail tuna in Australia, but rather to compare: i) the efficacy of each method to access specialised longtail tuna fishers within the general population in the absence of a list frame of participants, ii) the profiles of specialised fishers (e.g. gender, preferred fishing methods, avidity, club membership) recruited by each method, and iii) the types of reasons why some fishers may refuse to participate in each of the surveys, in order to provide insights into possible biases to consider should a particular method be used on a larger scale for estimating total catch in future surveys.

Methods

Online diary

To administer the online diary survey, a website was created (www.longtailtuna.com.au) where fishers were asked to enter data for individual sport fishing trips undertaken between 17 December 2009 and 8 May 2010. This included trip date, fishing location (in 31 reporting regions shown in Figure 1), effort (in hours), numbers and sizes of longtail tuna caught and/or released. Fishers had the option of remaining anonymous, or registering on the website with their email address and offered the incentive of obtaining a single entry in a monthly prize draw for each fishing trip they reported. The website was extensively promoted nationally via radio, print media and website articles, and internet fishing forums. The website also served as an educational tool, where up-to-date information on longtail tuna biology and fisheries was made available.

The website was written in C#, using the ASP.NET MVC Libraries, and information entered on the website was automatically entered into a MySQL database hosted on an IIS 6.0 Web Server owned by the CSIRO.

Time-location sampling

TLS was undertaken over 26 days from 17 December 2009 at 26 different tackle stores at 15 locations around Australia (Fig. 1). Sampling was undertaken during a 3-hour period on weekends or on Thursday nights at locations where stores were open for late night trade. These times were regarded by the store owners to have the highest concentration of customers. Sampling these ‘high traffic’ times was preferred in this study as the primary objective was to test the efficacy of using TLS for intercepting the hard-to-reach proportion of the recreational fishing community. If expansion of catch rate data is required to estimate total recreational catch, a random stratified sampling survey design would be needed.

During each 3-hour survey, each store customer was intercepted as they exited the store. It was explained that a national survey on sport fishing was being undertaken that focused on longtail tuna. This approach was taken to gain a better understanding the proportion of tackle store customers who were sport or game fishers, but did not necessarily catch or target longtail tuna. A pilot survey revealed that explaining the survey was about sport fishing in general enhanced retention of fishers who initially declared to be ineligible. In many of these cases, fishers stated they did not target longtail tuna but later recalled that they did incidentally catch longtail tuna while targeting other species of sympatric coastal pelagic sport fish.

The proportion of sport fishers who were fishing club members was also determined. This was done because if the vast majority of sport fishers were members of a fishing club – and if fisher profiles and catch characteristics were similar between club members and non-club members – then more cost-effective methods could be employed in future studies. This may involve simply surveying members of fishing clubs, for which a complete list frame exists and a population size is known.

When an intercepted individual consented to participating in the survey, they were asked if they had fished for a predefined list of marine pelagic sport fish species in the previous 12 months. Although recall periods longer than three months are generally considered too long to accurately recall catch and effort (Lyle 1999), in this study we were primarily testing the efficacy of TLS to access the hard-to-reach participants in the specialised fishery. Nonetheless, in such specialised fisheries, captures are usually a rare and memorable event, and therefore recalled catch over the previous twelve month period may be less susceptible to recall bias than other recreational fisheries (Pollock et al. 1994).

In order to avoid double sampling of individuals on subsequent sampling occasions, intercepted individuals were asked if they had participated in the survey previously, and if so, were deemed ineligible to participate on the second occasion. However, this occurred in only one instance. Individuals who were ineligible or refused to participate were recorded as belonging to one of ten refusal/ineligibility categories. Eligible individuals were then invited to participate in a full survey that would take approximately 90 seconds to complete. Undertaking short interviews was considered important to minimise refusals and respondent burden. Also, the pilot survey indicated that busy customers became disinterested during longer interviews and appeared to provide responses that lacked candour in an attempt to expedite the interview, which has been documented in other types of surveys (Hansen 2007). Individuals agreeing to participate in the interview were asked to report information on the general locations of their fishing activities (e.g. Exmouth, Gulf of Carpentaria), fishing effort, and number of longtail tuna caught and/or released over the previous 12 months, even if zero. The TLS survey had many of the same questions as the online survey, although not all of the online survey questions could be asked in the TLS survey. This was due to interview time constraints and because TLS was a retrospective survey covering the previous 12-month period, whereas the online diary was a prospective survey where information was gathered after individual trips were completed.

Access point survey

An access point survey (APS) is an on-site method that involves intercepting fishers at points where they terminate a fishing trip, such as boat launching ramps, marinas, and in the case of land-based fishers, piers and rocky headlands. Fishers are intercepted as they leave the fishery on completion of their trip. This type of method has the advantage of being able to collect high resolution species-specific information on numbers and size composition of fish caught because the catch can be viewed – with the fisher's permission – by survey staff. Furthermore, recall bias for catch and effort is minimised because the fisher is intercepted immediately at the end of the trip rather than days or months later, which can be the case for some diary or recall surveys. However, an APS has the disadvantage of being labour-intensive and very expensive due to the enormous sampling effort required to comprehensively sample all access points across large spatial and temporal scales.

Although the study aimed to undertake a national survey of recreational longtail tuna catches, resource constraints prohibited the implementation of a large-scale access point survey around Australia. Instead, we undertook an APS at four popular public boat-launching ramps within reporting zones 6 and 7 (Fig. 1) to compare its efficacy for intercepting longtail tuna fishers.

Stratified random sampling was used where survey day was regarded as the primary sampling unit. The survey design was stratified by boat ramp location (Mooloolaba, Scarborough, Manly and Tweed Heads), day type (stratified and weighted by weekday and weekend/public holiday), and month during the survey period (2 January 2010 to 8 May 2010). Replication of survey days were weighted so that 60% of sampling occurred on weekends or public holidays (with 40% on week days) to weight in favour of the increased fishing participation at these times.

Prior to the APS, observations of boat traffic at each boat ramp were made on each day type for the entire summer daylight period (approximately 0400–1700 hrs) to determine peak boat retrieval times throughout the day. Survey times were then selected to align with these peak times, so that 65% of daylight hours were surveyed, which approximately corresponds with 85–90% of the total daylight boat traffic. Survey shift times were adjusted each month to correspond with seasonal changes in daylight duration.

On each survey day, individuals were intercepted as they retrieved their boats and asked to participate in the survey. Once it was determined that an individual was a sport fisher and they agreed to participate in the survey, they were asked questions relating to their sport fishing catch and effort and other profile information such as whether or not they were a member of a fishing club. Respondents were also asked if their catch of longtail tuna could be inspected to validate species identification and record the size of each fish retained, or to estimate the total length of longtail tuna that were released.

Statistical analyses

Since the population size of specialised longtail tuna fishers was not known and difficult to estimate due to the absence of a list frame (see 'Discussion'), we assessed the three survey methods by comparing catch rates (number of fish hr^{-1}) rather than estimated total catch. Because all three methods obtained catch and effort information for completed trips, the catch rate, $\hat{R}$, was calculated for each method using the ratio of means (Pollock et al. 1994), which can be represented as:

$$\hat{R} = \frac{\sum_{i=1}^{n} c_i / n}{\sum_{i=1}^{n} L_i / n}$$

where c_i is the number of longtail tuna caught during an individual trip of duration L (in hours) in sampling strata i, by the number of fishers surveyed, n. For the TLS survey, L was the summed effort of all trips undertaken over the previous year.

A one-factor analysis of variance (ANOVA) was used to test for differences in the catch rates between the three methods, with the factor of method considered fixed. Data were examined for normality and homoscedasticity of variances using Shapiro-Wilk and Cochran's test, respectively. Since the data were highly skewed towards zero (i.e. many fishers catching zero fish), data were $\log_{10}$ (x+1) transformed prior to analysis. Student-Newman-Keuls (SNK) test was used for a posterior comparison of means.

A Kolmogorov-Smirnov (K-S) test was used to delineate whether statistical differences occurred between the length-frequency distributions of longtail tuna collected using each method.

Estimating survey costs

We calculated the cost of conducting a single annual national survey using each survey type having an effect size of 0.5 to detect statistical differences in annual catch rate estimates based on the results of the present survey. It should be noted that a single survey is likely to only provide an estimate of the catch from the sampled population, which may provide an index of catch-per-unit-effort (CPUE) that can be used in some types of stock assessments. Therefore, other methods are required to estimate the total number of participants in the fishery in order to estimate the total recreational catch and are not considered here.

In the costing scenarios for undertaking a national survey of longtail tuna fishers, labour costs were based on the daily wage of a CSIRO CSOF 5.1 for the Principal Scientist and statistician, and a CSOF 3.1 for field and technical staff. The estimated costs should be considered minimum estimates that do not include additional salary, travel and operating costs in the case of poor weather and other unforeseen circumstances. Such contingencies would almost certainly add to overall costs.

Results

Time-location sampling

A total of 1536 individuals (1227 males; 309 females) were intercepted over 26 days of sampling using TLS. An additional 141 individuals (123 males; 19 females) were recorded but were unable to be intercepted due to field staff already conducting interviews with other individuals. Of the individuals intercepted, 1141 (74%) were ineligible to participate in the survey as they did not sport fish, 125 (8%) refused to participate, and 270 (18%; 255 males and 15 females) were eligible for the survey as they had fished for sport or game fish in the past 12 months. Of these eligible fishers, none refused to participate in an interview. Of the 1141 ineligible individuals, 882 (77%) were males, of which 64% did not sport fish, and 23% had not sport fished in the previous 12 months. In contrast, of the 259 (23%) females intercepted, 53% did not fish and 36% did not sport fish (Fig. 2).

Online diary

A total of 107 individuals registered as diarists on the website, of which 49 (46%) submitted data for at least one fishing trip. The remaining 58 registered usernames were assumed to belong to different individuals who were part of the longtail tuna recreational fishery but did not fish for longtail tuna during the study period. A further 49 fishing trips were reported anonymously. Although it was not possible to determine how many individuals contributed this information, since they did not register, for the purposes of this study it was assumed each trip was submitted by a different individual. Therefore, a total of 156 individuals were assumed to have contributed, or intended to contribute, information through the online diary.

Access point survey

Access point surveys were conducted over 41 days at Mooloolaba (12 days) Scarborough (11), Manly (9) and Tweed Heads (9) between 3 January 2010 and 9 May 2010. Overall, 1339 vessels were intercepted at boat ramps. Although interviews were conducted with one nominated person from each boat, these interviews represented the activities of 2908 individuals (2419 males and 489 females). Only 13 individuals (0.5%) refused to be interviewed. Overall, 2341 (80.5%) individuals from 981 (73.3%) vessels were fishers, and of these, 765 (32.7%) individuals from 326 (33.2%) vessels were sport fishers.

Survey refusals

Of the 125 individuals who refused to participate in TLS, most gave the excuse of being ‘too busy’ or ‘not interested in participating’, while a few males refused participation on the basis of language difficulties. Only one individual refused to participate for political reasons, which was related to the recent establishment of a Marine Protected Area. Three individuals refused because they primarily fished commercially, or because they had been interviewed on a previous occasion at a different store. It was unknown how many eligible fishers may have provided polite or ‘soft’ refusals by stating that they did not sport fish to avoid taking part in the survey. In contrast to TLS, fishers refused to participate in APS primarily due to political reasons and not being interested (Fig. 3). Reasons for survey refusals could not be determined for the online dairy survey since non-respondents are unidentifiable.

Fishing methods used

Overall, 96% and 100% of sport fishers surveyed by TLS and APS indicated that their primary mode of fishing was from a boat, compared to 27% of online diarists. The most popular methods for targeting longtail tuna by TLS and APS respondents were boat-based fishing using trolled lures, live/deadbait, and casting lures (Fig. 4). Despite longtail tuna apparently being a primary target species for many saltwater fly fishers, this method was only used by 2% of respondents (Fig. 4). In contrast to TLS and APS respondents, the most popular methods used by online diarists were land-based fishing methods, primarily lure casting and live/deadbait (Fig. 4).

Catch and effort

A summary of the total catch and effort and average trip duration recorded by each of the three methods is shown in Table 1. The highest number of longtail tuna caught was recorded in TLS (750) from 22471 hours of effort from 4092 sport fishing days. In contrast, only 7 longtail tuna were recorded in APS from 1344 hours of effort from 326 sport fishing days. In comparison to APS, the online diary method accounted for fewer fishing days (178), similar fishing effort (1323 hours), but 178 longtail tuna were reported.

A one-way ANOVA revealed a significant difference in mean catch rate of fishers surveyed in each survey method (F=4.134; df=2; P=0.001). The mean catch rate in APS (0.006 ± SE 0.002 fish hr^{-1}) was significantly lower than for TLS (0.090 ± 0.019 fish hr^{-1}) and the online diary (0.143 ± 0.029 fish hr^{-1}) (Fig. 5; SNK test).

Similarly, a one-way ANOVA revealed a significant difference in the mean trip duration of respondents sampled using each survey method (F=2.211; df=2; P=0.031). The mean trip duration of online diarists (7.6 ± 0.3 hr) was significantly higher that respondents in TLS (4.8 ± 0.12 hrs) and APS (3.8 ± 2.1 hr) (Fig. 5; SNK test).

Fisher avidity and fishing club membership

The avidity of fishers differed markedly among sampling methods. The majority of fishers (65%) in TLS fished for <10 days in the previous 12 months, whereas online diarists and APS respondents had similarly higher avidity levels, with the majority of participants fishing for 10-30 and >30 days (Fig. 6). Overall, 21.9%, 12.7% and 15.3% of respondents in TLS, the online diary and APS were members of a fishing club, respectively. However, the proportion of fishing club members decreased with increasing avidity for TLS, but remained relatively constant with avidity for the online diary and APS (Fig. 6).

Contributions to the overall effort and catch of surveyed fishers increased with increasing avidity with this trend being more prominent for TLS and APS (Fig. 7). The 169 respondents in the TLS survey who fished for <10 days contributed only 11% and 21% to the overall effort and catch, respectively. In contrast, the 22 fishers who fished for >30 days contributed 61% and 43% to the overall effort and catch, respectively.

Size composition of fish from all methods

Lengths of fish reported in online diaries to have been caught or released ranged from 34 to 150 cm TL, with the majority of fish being between 85 and 120 cm TL (Fig. 8). Lengths of the seven fish recorded by scientific staff during APS (80-87 cm FL) were within the size range of fish reported by online diarists (Fig. 8). Lengths of fish caught by respondents in TLS were not collected.

Comparison of survey costs and efficacy

Estimated costs for undertaking a single national recreational catch survey for longtail tuna using each survey type is shown in Table 1. The online diary method was estimated to be the most inexpensive sampling method, due to low labour, travel and operating costs. This method sampled the highest number of fishing days and yielded the highest proportion of sport fishers. However, this method surveyed the lowest number of individuals, fishing trips and hours fished, but had the highest catch rates (0.143 ± 0.366 fish hr^{-1}).

APS was estimated to be the most expensive survey method where a total of only 7 longtail tuna were recorded which yielded the lowest catch rate (0.006 fish hr^{-1}). APS intercepted the highest number of individuals and sport fishers, although it surveyed only a small number of fishing trips, and the shortest average fishing trips.

TLS using a recall survey was a reasonably low-cost sampling method that was conducted for the shortest period, yet sampled the largest number of fishing trips and hours fished by sport fishers, and recorded the largest number of longtail tuna captures.

Discussion

The increasing diversification of the recreational fishing sector and the need for reliable information for decision-making has highlighted a need to develop cost-effective methods that can obtain representative data from hard-to-reach components of recreational fisheries, which may contribute substantially to the overall recreational catch for some species. The present study assessed the efficacy of time-location sampling, online diaries and access point surveys for obtaining representative recreational catch and effort data from specialised fishers in the recreational longtail tuna fishery.

Specialised fisher profiles

The population of specialised fishers comprising the recreational longtail tuna fishery in the present study were characterised as generally being males who were not members of a fishing club. The three survey methods showed that fishers generally fished for less than 10 days per year, where the average trip lasted 5.4 hours and specialised equipment and techniques were employed such as trolling lures, casting lures, and using live bait.

There are few studies that have specifically surveyed fishers who specialise in targeting large pelagic fish, but Morton and Lyle (2003) obtained similar results from a diary survey of the specialised offshore game fish fishery in Tasmania, which primarily targets southern bluefin tuna (*Thunnus maccoyii*). They found 97% of fishers were male, 33% of respondents were members of a fishing club, and fishers undertook an average of 7 trips per year, lasting around 7 hours per trip.

Interestingly, specialised fishers in the present study undertook a similar number of trips as unspecialised fishers in a nation-wide survey in Australia (6 days yr^{-1}) (Henry and Lyle 2003) but substantially fewer than unspecialised fishers in Canada (13 days yr^{-1}) (FOC 2007), the US (17 days yr^{-1}) (U.S. Department of the Interior 2006) and South Africa (37 days yr^{-1}) (Brouwer and Buxton 2002). However, Henry and Lyle (2003) found that the most avid 3% of Australian fishers – who fished for more than 25 days per year – constituted 20% of the total recreational fishing effort in Australia. In the present study, we found that the 12% of specialised longtail tuna fishers who fished for more than 30 days contributed 61% and 43% to the total effort and catch of TLS respondents, respectively. These results highlight that sub-components exist even within relatively small and highly specialised components of recreational fisheries. These minority groups can have a disproportionately large influence on total effort and catch estimates and therefore, need to be adequately represented in surveys.

Accessing these minority groups is a significant challenge in the absence of a complete list frame of fishers. However, there is a common perception that sport fishers are generally members of fishing clubs, who could therefore be cost-effectively surveyed using traditional random sampling techniques to select and contact fishers using membership lists obtained with permission from fishing club officials. Unfortunately, club members are rarely representative of the entire recreational fishing population since they generally fish more frequently and are often more skilled than non-club members (Gigliotti and Peyton 1993, Fisher 1997, Gartside et al. 1999), and have different attitudes and behavioural characteristics (Wilde et al. 1992). Therefore, we explicitly sought to determine the proportion and characteristics of fishing club and non-club members in our surveys.

Our results revealed that club membership ranged between 13-22% – depending upon the survey method used – and is similar to other specialised recreational fisheries for sport fish including black bass (Wilde et al. 1998) and stream trout (Gigliotti and Peyton 1993). Although this percentage is appreciably higher than the national fishing club membership for the overall recreational fishing sector in Australia (4.3%) (Henry and Lyle 2003), the vast majority of longtail tuna fishers were not club members who also tended to fish less frequently than club members. Therefore, surveys that exclusively employ club membership lists are unlikely to attain a representative sample of specialised fishers, and would ultimately bias catch and effort estimates if extrapolated to the entire number of participants in the fishery.

The specialised recreational fishery for longtail tuna was characterised by low catch rates, where fishers caught – averaged across all three survey types – 0.08 fish hr^{-1}, or one fish for every 11 hours of effort. This catch rate is about an order of magnitude higher than the catch rates of other pelagic fish caught by sport fishers such as yellowtail kingfish (0.008-0.018 fish hr^{-1}), black marlin and striped marlin off eastern Australia (0.008-0.043 fish hr^{-1}) (Lowry and Murphy 2003, Lowry et al. 2006), and southern bluefin tuna and yellowfin tuna off Tasmania (0.005-0.008 fish hr^{-1}) (Morton and Lyle 2003). The higher catch rates of longtail tuna may be explained by the effectiveness of time-location sampling for surveying the proportion of the population that may catch longtail tuna. The access point survey undertaken in the present study recorded low catch rates for longtail tuna (0.006 fish hr^{-1}), which were similar to catch rates recorded for other sport fish by Lowry et al. (2006) and Morton and Lyle (2003) using similar survey methods. This is likely to be a result of many zero catches by fishers since the sampling method is only capable of intercepting a small fraction of fishing trips by longtail tuna fishers, of which a large proportion (74% in TLS) are unsuccessful.

Online diary

The online diary method was the most inexpensive sampling method for undertaking large-scale sampling of individual fishing trips. This was primarily due to relatively low labour and operating costs since this method avoids unnecessary sampling of individuals who may not fish, since only longtail tuna fishers submit data. However, voluntary participation can introduce several types of biases that are not easily detected or tested for since no list frame exists to determine the number or characteristics of non-respondents in follow-up surveys (Fisher 1996). It was apparent that some types of biases were evident in the online diary survey since the composition of fishers, catch rates and effort differed markedly to fishers sampled using other methods.

'Voluteerism', or 'response', bias is one type of bias that may compromise results from online surveys, whereby the sample is biased towards more cooperative individuals, who are also likely to be the more active members of populations who recognise the value of survey participation (Wang et al. 2005, Couper 2007, Raymond et al. 2010). In recreational fisheries this may lead to avidity bias, which appeared evident in the present study where online diarists generally reported fishing for 10-30 days yr^{-1}. In contrast, the majority of TLS respondents fished less than 10 days yr^{-1}, which more closely aligns with previous national effort estimates of 6 days yr^{-1} in Australia (Henry and Lyle 2003).

The average trip duration of online diarists (7.6 hrs) was also longer than for respondents in TLS (4.8 hr) and APS (3.8 hrs). On closer inspection, a large majority (73%) of online diarists were land-based fishers. Long trip durations are characteristic of the land-based fisheries (see Brouwer and Buxton 2002, Rangel and Erzini 2007), since fishers are largely stationary on the shoreline and rely on a high expenditure of effort in order to increase their chance of intercepting fish as they move along the coast. Therefore, these results suggest the possibility of 'differential recruitment' bias (Magnani et al. 2005, Heckathorn 2007); a recruitment pattern where sub-components of a population are disproportionately represented in a sample. Land-based fishers in Australia generally do not have a large variety of large pelagic species to target, and so longtail tuna are one of the primary targets due to their relatively high abundance in shallow coastal waters. Consequently, this group of fishers are strong advocates for ensuring the sustainability of longtail tuna. This group of fishers also appear to be socially connected through personal contacts and dedicated internet forums (e.g. www.sportfishextreme.com), therefore existence and advertisement of the online diary probably reached a large proportion of this small population more rapidly than other components of the sport fishing community.

In the few studies that have surveyed land-based recreational fisheries, the catch rates are generally very low in comparison to boat-based fisheries. For example, along South Africa's Eastern Cape the catch rate of land-based fishers (2.06 fish day^{-1}) was less than half that of the boat-based fishery (5.3 fish day^{-1}) (Brouwer and Buxton 2002). Similarly, in Portugal the average catch rate of land-based fishers was 0.5 fish hr^{1} (Rangel and Erzini 2007). This probably explains why few fishers appear to target pelagic fish from the shore in Australia, which is reflected in the TLS survey where all components of the fishery were represented but where land-based fishers comprised only 4% of sport fishers.

Interestingly, the catch rate by online diarists was nearly double and twenty-five times that of TLS and APS respondents, respectively. The online diary method may therefore also suffer from non-reporting and/or prestige biases, but it is difficult to speculate which bias is more likely. Non-reporting bias is common in diary surveys since respondents frequently forget to record every fishing trip. This problem has been addressed in recent telephone-diary surveys in Australia with the use of 'memory jogger' calls, where survey staff frequently contact diarists to record the respondent's fishing activities since their previous contact (Lyle et al. 2002). In contrast, land-based sport fishing is dangerous and requires a high level of skill – since a large pelagic fish cannot be pursued in a boat once hooked – and there is a high degree of prestige associated with the capture of species such as longtail tuna. As a result, fishers may not report unsuccessful trips in order to give the appearance that their personal catch rates are higher than other respondents. A further indicator of prestige bias in the online diaries may be seen in the size estimates of reported fish, where several fish were reported to be well above the maximum recorded size of longtail tuna (130 cm TL) (Froese and Pauly 2009).

The apparent differences in attitudes of sub-components of the recreational longtail tuna fishery, underlies an elevated potential to incur avidity, prestige and volunteerism biases using the online diary method. Because there is no list frame of fishers who could potentially submit data, there is no way of knowing if a representative sample of fishers is being collected, or understanding specific biases such as non-response (Fisher 1996). We are aware of no study of recreational or commercial fisheries that have quantitatively assessed non-response in online surveys. However, in an epidemiological study, Raymond et al. (2010) compared TLS and online for surveying a hard-to-reach population of males who have sex with males (MSM). Despite subjects being recruited from face-to-face interviews using TLS where refusals were zero, the response rate of the same participants who we asked to complete a subsequent online survey was

63%. Furthermore, the demographic and behavioural characteristics of online survey participants were less diverse.

Because of the large risks in incurring significant biases that cannot be easily or cost-effectively corrected, this method can only be capable of collecting a 'convenience sample' and is not recommended as a sampling method for collecting quantitative data from specialised recreational fisheries for inclusion in stock assessment or decision-making processes.

Access point surveys

Access point surveys were the most expensive method for surveying specialised longtail tuna fishers. However, this method allows collection of high quality species-specific catch, effort and size distribution data, which are least affected by recall and many other types of biases because fishers are interviewed immediately at the end of their fishing trip (Pollock et al. 1994). Other methods that rely on fishers to recall information have been shown to incur recall bias, particularly for effort. For example, Lyle (1999) found that effort estimates provided by respondents in a 12-month recall survey of specialised recreational lobster fishers were about twice that of diarists in a concurrent diary survey.

In the present study, there was no difference in effort – in terms of trip duration – between TLS and APS respondents, indicating that TLS may be a viable cost-effective alternative to expensive APS. Furthermore, APS excluded the land-based component of the longtail tuna fishery, which although is apparently small, appears to expend a high level of effort and probably contributes to a reasonable proportion of the total recreational catch. If the land-based fishery was to be included in an APS, a separate on-site roving creel survey would be required, which would probably incur similar costs as the APS for boat-based fishers.

Surprisingly, APS intercepted the highest number of sport fishers, which may be explained by the fact that each sport fishing boat intercepted generally carried more than one sport fisher. However, access point surveys can only survey individual trips, and therefore, the sampling effort required to represent the annual catch and effort for longtail tuna is high. For example, only 7 longtail tuna captures were recorded in 41 days of sampling, which resulted in this method yielding the lowest catch rate of 0.006 fish hr^{-1}. This catch rate was very similar to the low catch rates obtained in other on-site sport fishing surveys (Lowry and Murphy 2003, Lowry et al. 2006). The sampling cost to obtain representative data from the fishery across a spatial scale that is relevant for a pelagic species such as longtail tuna is too high for this method to be considered as a cost-effective option for a long-term monitoring program. However, high resolution data collected from on-site surveys such as APS are essential for quantifying biases to allow for correction in estimates obtained from off-site surveys (e.g. recall surveys and diaries).

Time-location sampling

Our study demonstrated that TLS conducted at fishing tackle stores and using a 12-month recall survey – herein termed “TLS-Recall” – is a reasonably low-cost sampling method that can rapidly access the breadth of specialised sport fishers who represent a range of avidity levels and across large spatial scales. It is important to note that catch and effort estimates can be affected by recall bias since the ability of fishers to recall specific fishing trips generally declines after two months (Tarrant et al., 1993; Pollock et al., 1994). The effect of recall bias is not a significant issue in the present study, since our primary objective was to assess the efficacy of TLS to intercept hard-to-reach specialist sport fishers within the wider community. However, recall bias is an important consideration if TLS-Recall is used with an intention to gather representative data for stock assessment. In the present study, there was no statistical difference in effort – in terms of trip duration – between TLS and APS respondents, indicating that effort estimates by TLS respondents are reasonably accurate. With respect to catch estimates, recall bias in a 12-month recall survey may not be a significant issue when a capture is a rare or memorable event (Pollock et al., 1994), which is generally the case for longtail tuna.

A further consideration besides recall bias is that long recall periods may introduce telescoping bias, whereby a fisher incorrectly includes a memorable event that occurred outside the 12-month survey period (Pollock et al. 1994). Telescoping bias may be reduced by providing easily recognised reference dates defining the beginning of the sampling period, such as ‘New Years Day’, choosing recall periods that directly relate to particular “fishing seasons”, and avoiding any date that may occur during major holiday periods when fishers are more likely to be active.

The TLS-Recall survey design could be modified to reduce recall and telescoping bias by using multiple TLS surveys with shorter recall periods (e.g. 2-3 months). The TLS-Recall design could be improved to collect higher resolution data for individual trips and also reduce recall bias – albeit at a higher cost – if used in combination with a diary survey. To this end, we propose a

"TLS-Dairy" complemented survey design that could use TLS to cost-effectively recruit a representative sample of fishers – which cannot be achieved in the absence of a complete list frame – to complete a fishing diary over the desired survey period. Because the initial recruitment is via face-to-face interviews, the level of non-response and refusals can be quantified and corrected for, unlike online surveys.

Conventional diary surveys can experience high attrition of respondents and accuracy and non-reporting issues, particularly over long survey periods (Pollock et al. 1994). These problems may be reduced by using a telephone-dairy approach where the burden of data collection resides upon the researcher, who contacts the respondents recruited via TLS on a regular basis to recall their fishing trip details (see Lyle et al. 2002). This is also likely to reduce recall bias since the time between the trip being undertaken and the details recorded by the researcher is minimised. The TLS-Diary approach approximately triples the cost of TLS-Recall approach due to additional labour required for ongoing contact with respondents on at least a monthly basis. However, TLS-Diary is likely to yield higher quality trip-specific information and is estimated to be about half the cost of an access point survey, which would not be representative of the entire fishery since the important land-based component in this fishery would be excluded.

Extension of TLS for estimating total recreational catch

Our results have shown that TLS can provide a representative sample of the catch and effort from specialised recreational fisheries. Unfortunately, TLS surveys alone cannot directly estimate population size in order to expand sample data to provide an estimate of the total recreational catch of particular species, such as longtail tuna. In most large-scale recreational fishing surveys that aim to estimate the total recreational catch of particular species, a large-scale general population telephone survey is undertaken to estimate the proportion of the population who are active recreational fishers (Lyle et al. 2002, U.S. Department of the Interior 2006, FOC 2007). Unfortunately, this is often not possible for small hard-to-reach sport fishing populations, such as recreational longtail tuna fishers, since the high sampling effort required to intercept these rare fishers make the survey cost prohibitive (Teisl and Boyle, 1997).

However, with further development, fisher population size may be estimated using capture-recapture techniques in multiple TLS surveys, similar to the "RDS-Recapture" approach recently described by Griffiths et al. (2010) for accessing hard-to-reach recreational fishers using respondent-driven sampling (RDS). This may be achieved by undertaking multiple surveys at a probability sample of sites within a sampling universe. The first TLS survey would serve as an initial 'tagging' event where respondents would be asked for unique identifying features, or 'soft measures' of identity (e.g. first name, birth date, home postcode). Using a combination of soft measures as a means of post-survey identification of respondents has the advantage of reducing masking bias or intentional deception by more distrustful members of the population. This can arise when asking respondents for private details, or 'hard measures' of identity (e.g. divers licence or social security number), which they may be reluctant to disclose for fear of loss of anonymity or information being on-sold to a third party (Heckathorn et al. 2001). Subsequent TLS surveys would serve as 'recapture' surveys where the number of 'recaptured' respondents would be recorded. It may then be possible to use capture-recapture models to estimate population size, which has been successful for other hard-to-reach populations that lack a list frame such as homeless persons (Dávid and Snijders, 2002) and HIV-infected drug users (Mastro et al., 1994).

Estimates of population size may be compromised if there is significant heterogeneity with capture probabilities of fishers. This may occur in instances where members of the target population move extensively between several tackle stores, or visit tackle stores frequently, therefore have a higher probability of capture. Targeted studies on the patterns of venue use by fishers would be required to resolve this concern. Conversely, some fishers may purchase the majority of their tackle online or in other countries where product availability or foreign currency exchange rates are more favourable, therefore their capture probability in a TLS survey is effectively zero. However, during the course of the survey, tackle store owners indicated that these types of consumers are still likely to enter tackle stores at some point to purchase minor items (e.g. hooks, bait), or to simply inspect particular products before purchasing them elsewhere. Therefore, if TLS is used with the appropriate spatial and temporal stratification, a representative sample from the target population may be cost-effectively attained.

Conclusions

The increasing efficiency and diversification of recreational fisheries worldwide poses increasingly difficult challenges for researchers to obtain robust data that are representative of the overall fishery that can be used in decision-making processes. In this paper we introduced two new methods – time-location sampling and online diaries – for accessing the hard-to-reach components of recreational fisheries (e.g. sport fishers) that often lack a complete list frame of participants who are too rare within the general population to be cost-effectively sampled using traditional survey methods. We demonstrated that online diaries suffer from significant biases and are not reliable for collecting representative data. In contrast, TLS may be a cost-effective alternative to other traditional survey methods and can access the breath of fisher types within these hard-to-reach populations. TLS is not without its own potential biases however, but by demonstrating its efficacy for accessing these specialised fishers we hope that further research can build on our approach to eventually provide researchers with a cost-effective and reliable alternative to traditional methods that are likely to become increasingly ineffective in the future with increasing diversification within the recreational sector and the difficulty in reaching the target population in telephone surveys due to increasing non-contact, non-response and refusal rates.

Acknowledgements

This study comprises part of FRDC project 2008/058 "Biology, fisheries and status of longtail tuna (*Thunnus tonggol*), with special reference to recreational fisheries in Australian waters" funded by the Fisheries Research and Development Corporation, CSIRO Marine and Atmospheric Research, Recfish Australia, Recfishing Research, the Australian National Sport Fishing Association, the Amateur Fisherman's Association of the Northern Territory, the Australian Fishing Trade Association, Sunfish Queensland, and the NSW Recreational Fishing Trust. The access point survey component comprises part of a PhD by Mitchell Zischke. We are grateful to Diana Reale (CSIRO) for the website design; Bryony Bennett, Meg Rive and Glen Paul (CSIRO), Tim Simpson (Bluewater Boats and Sportfishing magazine), Ben Collins (ABC Radio Kimberly), Michael Mihajlov and Kurt Edwards (Australian Land-based Angler Association) for assistance with communications and media releases. We are grateful for the support from tackle store managers who granted permission for surveys to be undertaken outside their stores, and volunteers conducting surveys including Quinton Dell, Kevin Charteris, Allan Petersen, Owen Li, Chris Hill, Chris Lacey, Jenny Gates, Judy Lynne, and Cathy Bassett. Finally, we would like to thank all of the fishers who participated in the surveys.

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Table 1. Comparison of sampling effort, fisher profiles, catch and effort and survey costs between time-location sampling (TLS), online diary (Web) and access point survey (APS) methods used in the present study.

Survey component	**Web**	**TLS**	**APS**	**Overall**
Total number of individuals intercepted	156	1536	2908	4600
Number (and %) of intercepted individuals who were fishers	156 (100)	1029 (67.0)	2341 (80.5)	3526 (76.7)
Number (and %) of intercepted individuals who were sport fishers	156 (100)	270 (17.6)	756 (26.3)	1182 (33.5)
Number (and %) of sport fishers who were fishing club members	9 (12.7)	59 (21.9)	117 (15.3)	185 (15.7)
Total fishing trips undertaken by respondents	178	4092	326	4596
Total number of hours fished by respondents	1323	22471	1344	25138
Mean (± SD) annual number of hours fished per year per respondent	20.5 (29.6)	83.2 (158.9)	-	51.9 (94.3)
Mean (± SD) fishing trip length (in hours)	7.6 (0.3)	4.8 (0.2)	3.8 (2.1)	5.4 (0.8)
Total number of longtail tuna caught (retained + released)	135	750	7	892
Mean (± SD) catch rate of longtail tuna (fish hr^{-1})	0.143 (0.366)	0.090 (0.315)	0.006 (0.067)	0.080 (0.703)
Estimated survey cost (AU$)	$8,885	$110,031	$362,800	

Figure Captions

Figure 1. Map showing the 31 reporting zones (in alternating shading) used for online diaries and the 15 locations where time-location sampling was undertaken at 26 different tackle stores. The access point survey was undertaken at four boat launching ramps in reporting zones 6 and 7.

Figure 2. Percentage of males and females intercepted during time-location sampling who were classified as ineligible to participate in the national longtail tuna survey. Numbers above bars denote number of individuals.

Figure 3. Percentage of respondents providing specific reasons why they refused to participate in the national longtail tuna survey after being intercepted during time-location sampling. Refusal reasons for the online diary method could not be determined.

Figure 4. Percentage of respondents utilising particular fishing methods for catching longtail tuna in Australia, as determined by time-location sampling of tackle store customers, access-point surveys and online diaries.

Figure 5. Mean (± 1SE) number of fish caught hr^{-1} and trip duration by fishers surveyed using time-location sampling (TLS), online diaries (Web) and access point surveys (APS).

Figure 6. Avidity of fishing club members and non-fishing club members (and both groups combined) surveyed using time-location sampling (TLS), online diaries (Web) and access point surveys (APS), quantified as number of days fished for sport fish in the 12 months prior to being interviewed. Numbers above bars denote number of respondents.

Figure 7. Percentage contribution of each fisher avidity class to the total effort and catch recorded using time-location sampling (TLS), online diary, and access point surveys (APS). Numbers above bars denote number of respondents in each avidity class.

Figure 8. Length-frequency distribution of longtail tuna estimated by fishers in time-location sampling and measured by scientific staff during access point surveys.

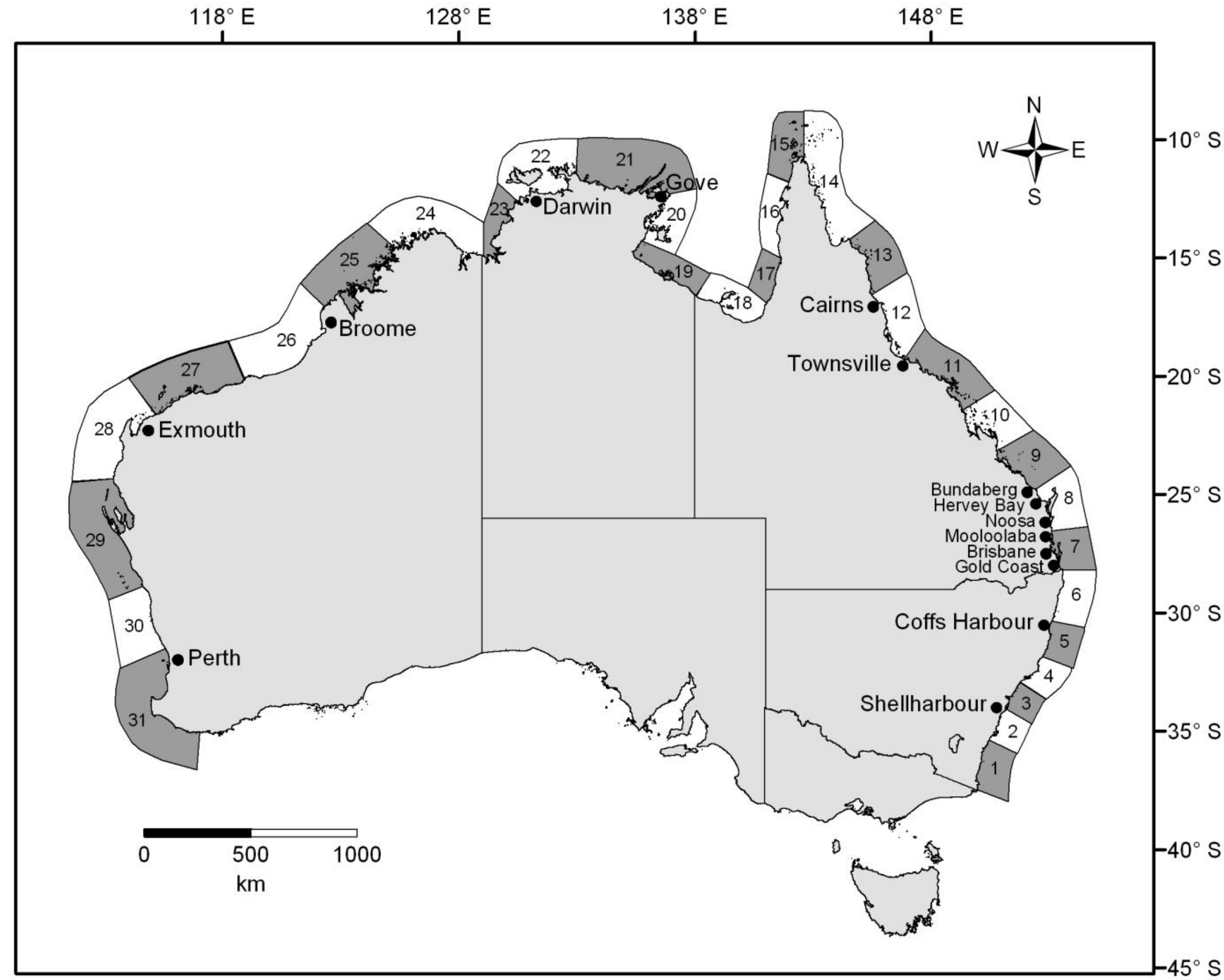
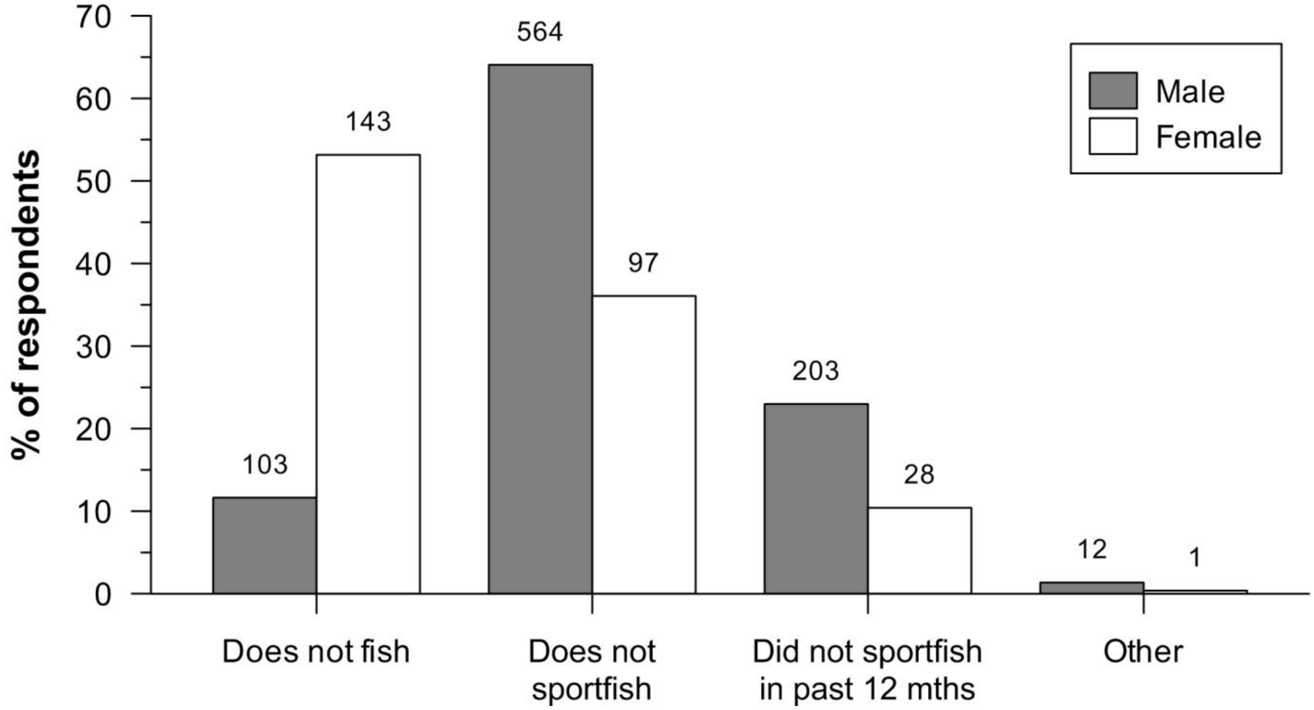

118° E
128° E
138° E
148° E
10° S
15° S
20° S
25° S
30° S
35° S
40° S
45° S
N
W
E
S
Darwin
Gove
Broome
Exmouth
Perth
Cairns
Townsville
Bundaberg
Hervey Bay
Noosa
Mooloolaba
Brisbane
Gold Coast
Coffs Harbour
Shellharbour
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
0
500
1000
km

Figure 1.



70
60
50
40
30
20
10
0
% of respondents
564
143
97
203
103
28
12
1
Male
Female
Does not fish
Does not sportfish
Did not sportfish in past 12 mths
Other

Figure 2.

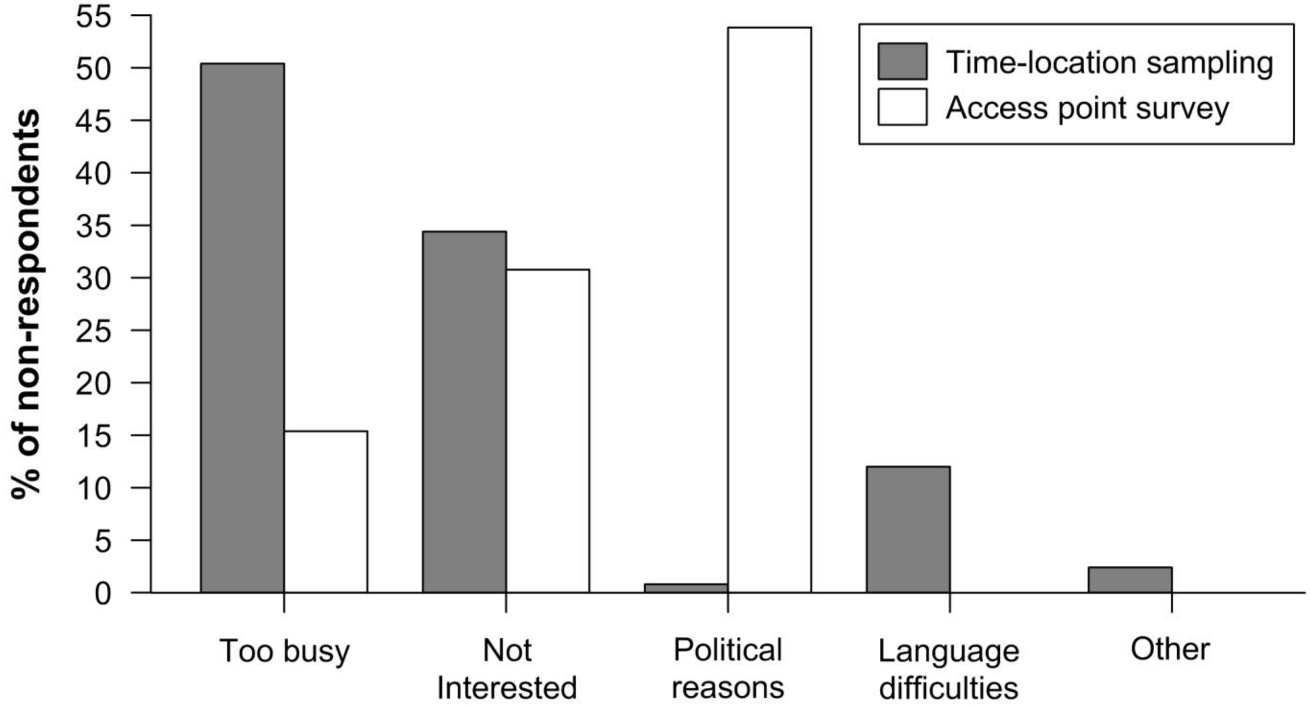

55
50
45
40
35
30
25
20
15
10
5
0
% of non-respondents
Time-location sampling
Access point survey
Too busy
Not Interested
Political reasons
Language difficulties
Other

Figure 3.

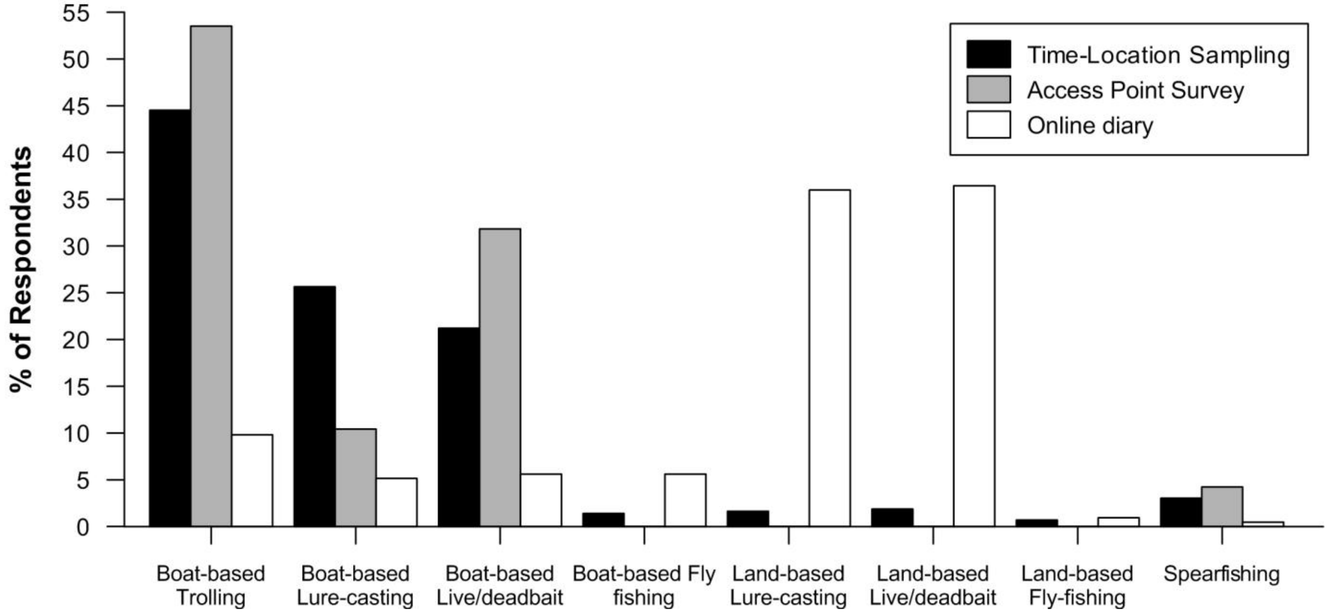

% of Respondents
55
50
45
40
35
30
25
20
15
10
5
0
Time-Location Sampling
Access Point Survey
Online diary
Boat-based Trolling
Boat-based Lure-casting
Boat-based Live/deadbait
Boat-based Fly fishing
Land-based Lure-casting
Land-based Live/deadbait
Land-based Fly-fishing
Spearfishing

Figure 4.

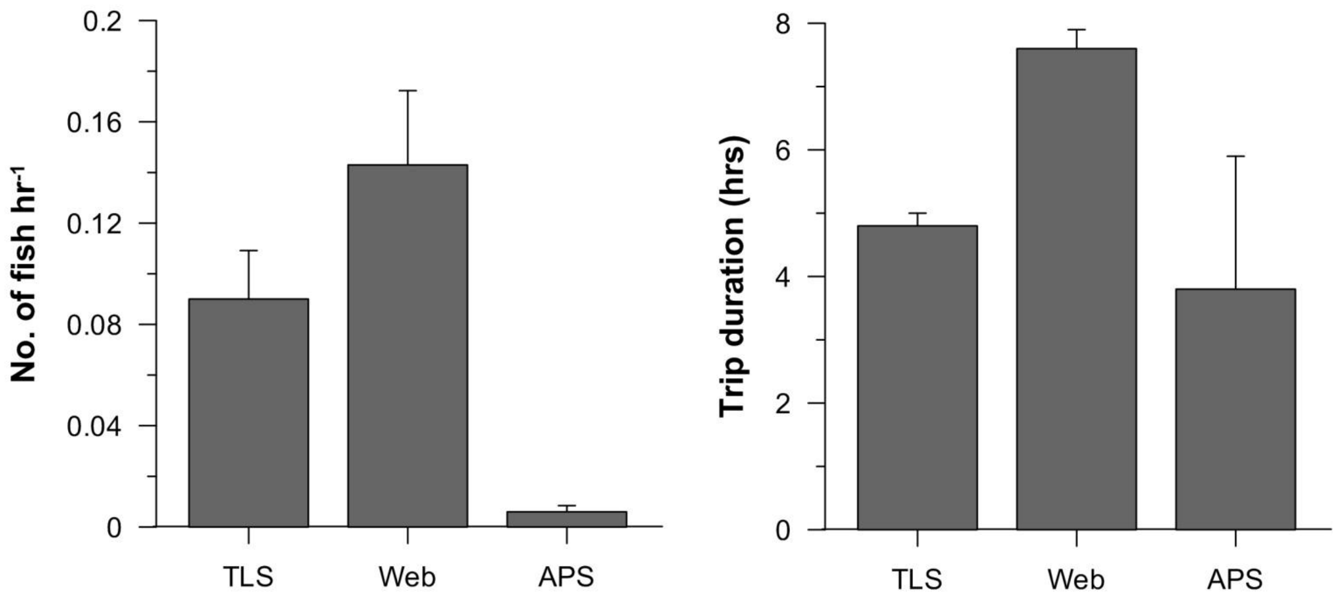
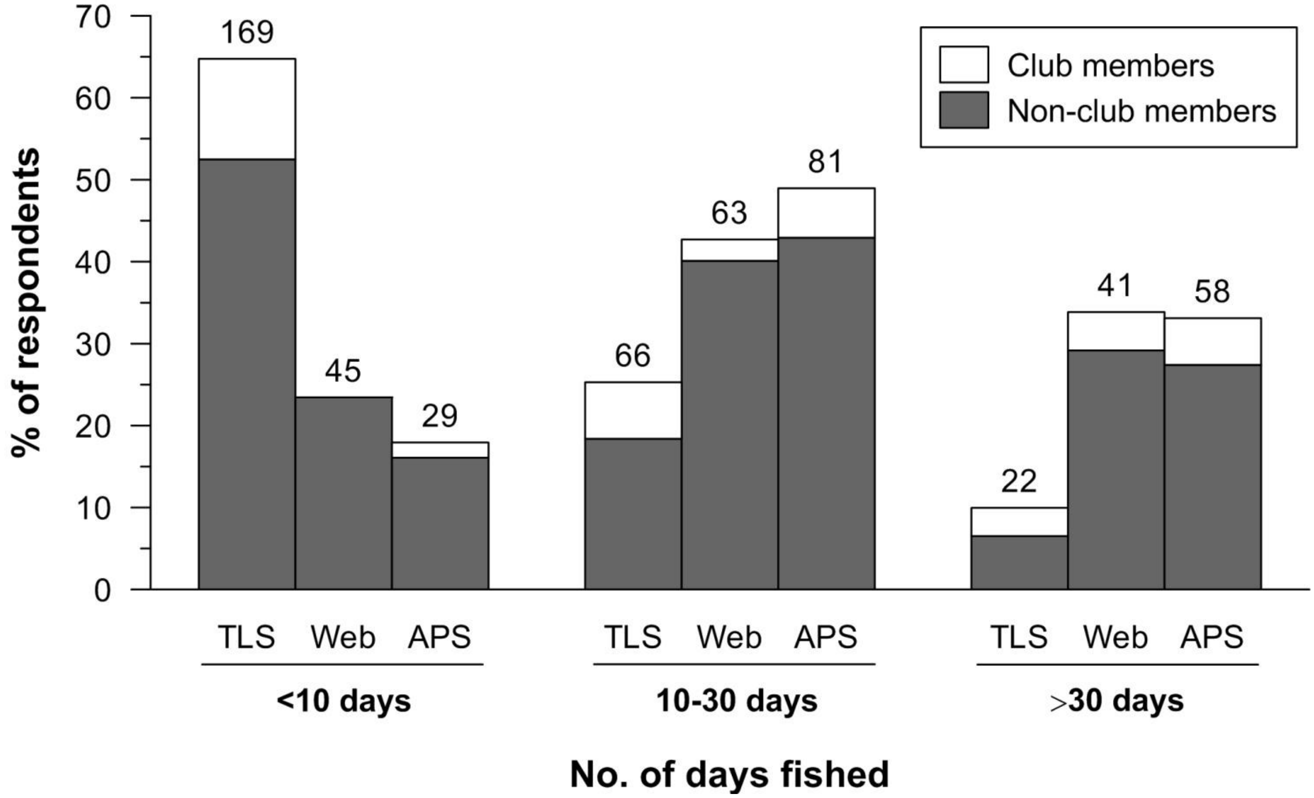

No. of fish hr-1
0.2
0.16
0.12
0.08
0.04
0
TLS
Web
APS
Trip duration (hrs)
8
6
4
2
0
TLS
Web
APS

Figure 5.



% of respondents
70
60
50
40
30
20
10
0
169
45
29
66
63
81
22
41
58
Club members
Non-club members
TLS
Web
APS
TLS
Web
APS
TLS
Web
APS
<10 days
10-30 days
>30 days
No. of days fished

Figure 6.

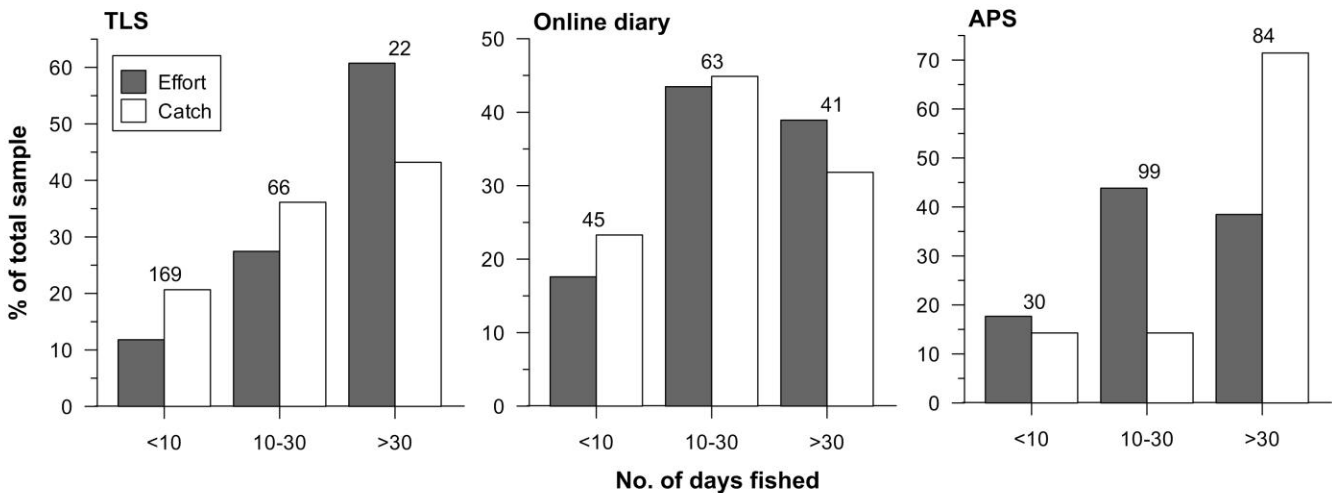

TLS
Effort
Catch
% of total sample
0
10
20
30
40
50
60
169
66
22
<10
10-30
>30
Online diary
0
10
20
30
40
50
45
63
41
<10
10-30
>30
No. of days fished
APS
0
10
20
30
40
50
60
70
30
99
84
<10
10-30
>30

Figure 7.

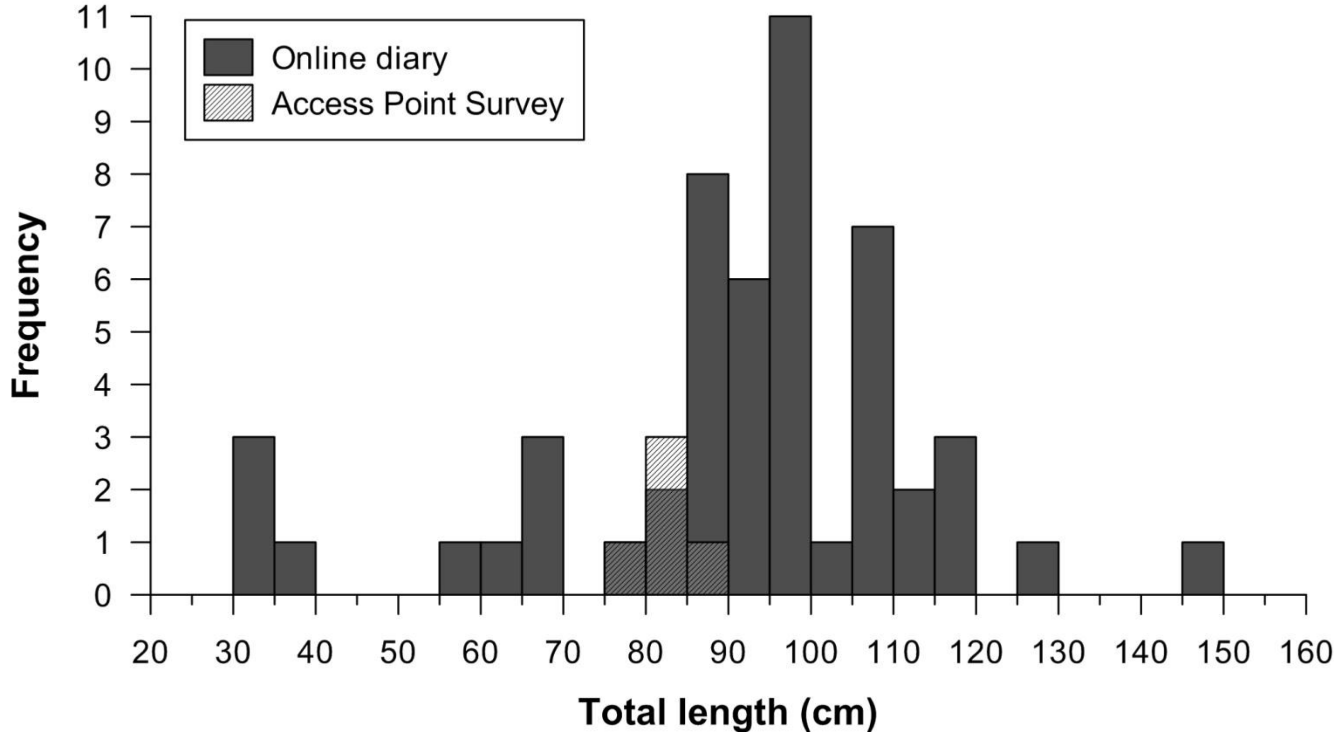

Online diary
Access Point Survey
Frequency
Total length (cm)
0
1
2
3
4
5
6
7
8
9
10
11
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Figure 8.