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Angling pressure impedes a three-year telemetry study on mulloway (*Argyrosomus japonicas*) in a western Victorian estuary, Southern Australia

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Abstract: Mulloway (*Argyrosomus japonicas*) are widely distributed in estuarine and nearshore waters within the Indian and Pacific Oceans. In Australia, it is an iconic recreational species that is also important commercially, with the largest commercial fishery being in the Murray River estuary and nearby coastal environments. To determine habitat preferences and movements between the estuary and the open ocean, 24 mulloway were acoustically tagged and followed for three years. Tagged fish were tracked using 20 receivers deployed along the estuary from its mouth to 65 km upstream. However, during the study thirteen (54%) of the tagged mulloway were caught and kept by anglers, hampering analysis of mulloway movements but providing opportunistic data on angling pressure and sizes of captured fish. Although generalised movement patterns could be gleaned from the remaining data, this case study exemplifies the challenges of telemetric studies of intensively angled fishes in estuaries and other semi-enclosed waters.

ABOUT THE AUTHOR

Jason Lieschke works for the Arthur Rylah Institute (ARI), the biodiversity research institute within Victorian government - Department of Environment, Land, Water and Planning (DELWP). The institute generates and shares knowledge, through world-class, applied, ecological research. This knowledge supports and guides sustainable ecosystem policy and management to ensure healthy, resilient ecosystems in south-eastern Australia. The Applied Aquatic Ecology section within ARI has extensive expertise in species and habitat assessment, monitoring and restoration; threatened species conservation and recovery; population dynamics and population modelling; disturbance ecology; ecological modelling, analysis and mapping; developing, testing and implementing innovative survey techniques for biodiversity assessment; developing robust indicators and decision support tools; taxonomy; and science communication. Jason's research includes threatened species, riverine flows, fish movement and estuarine electrofishing. This paper relates to species conservation, population dynamics and fish movement.

PUBLIC INTEREST STATEMENT

Mulloway (*Argyrosomus japonicas*) are an iconic recreational fish species in southern Australia. This study tagged 24 mulloway within the Glenelg River estuary, southwestern Victoria, Australia, and tracked their movements for three years to determine where in the estuary they moved and when they moved into and out of the estuary. Over 90% of fish that exited the estuary, exited between the months of November and January; four fish that exited were subsequently detected > 450 kilometres away, at or near the Coorong (Murray River mouth, South Australia), a known breeding location. However, during the study 13 (54%) of the tagged mulloway were caught and kept by anglers. Demonstrating the high intensity of angling pressure on mulloway in the Glenelg River estuary, revealing a serious risk of overfishing of juveniles and sub-adults in this estuarine habitat, which should prompt a review of legal size.

Subjects: Environment & Agriculture; Bioscience; Environmental Studies & Management

Keywords: acoustic telemetry; Argyrosomus japonicus; estuary; fish movement; fish habitat preference; recreational fishing pressure; Sciaenidae

1. Introduction

Mulloway, *Argyrosomus japonicas* (Sciaenidae), are widely distributed in the Indian and Pacific Oceans, occurring in estuarine and nearshore areas (Silberschneider & Gray, 2008). Within Australia, it occurs from the Burnett River in Queensland (153°13′E, 25°20′S) south around the continent to north-west Cape in Western Australia (114°01′E, 21°53′S) (Kailola et al., 1993), with four distinct sub-populations (Barnes et al., 2016). Fish in the Glenelg River and western Victoria belong to the same south-east sub-population as the Murray River estuary sub-population (Barnes et al., 2016) which supports a major commercial industry (Ferguson, Ward, & Geddes, 2008).

The species breeds in oceanic waters throughout south-eastern Australia. Small larvae have been collected in estuarine and coastal waters between February and April (Gray & Miskiewicz, 2000; Silberschneider & Gray, 2008) and from the Murray River sub-population from October to February, peaking in December (Ferguson, Ward, Ivey, & Barnes, 2014). Juveniles use estuaries as nursery habitat (Griffiths, 1996; Silberschneider & Gray, 2008) with recruitment driven by years with higher spring flows (Ferguson et al., 2008). Adults are often found around mouths of estuaries, in surf zones and along rocky reefs in offshore waters (Silberschneider & Gray, 2008). Mulloway sub-populations have variable growth rates, and Ferguson et al. (2014) suggest that the south-east Australian sub-population has a low growth rate and a larger size at maturity compared to other sub-populations.

In Australia, mulloway supports an important recreational fishery; over 975 tonnes of this "icon species" were taken by recreational anglers in 2000 (Henry & Lyle, 2003; Taylor, Laffan, Stewart-Fielder, & Suthers, 2006). Recreational fishing pressure focuses on nearshore and estuarine areas that are important nursery areas (McPhee, Leadbitter, & Skilleter, 2002). Mulloway is also commercially important, with the largest Australian fishery based in the Murray River estuary and nearby coastal environment (Ferguson et al., 2008).

To better manage the fishery by understanding habitat preferences and movements of this heavily fished species in the Glenelg River estuary, the present study employed acoustic telemetry for three years to track tagged mulloway. Initially, the aims were to assess (1) habitat preferences within the estuary and (2) movement patterns between the estuary and open ocean.

2. Methods

This study was conducted in the estuarine section of the 400-km long Glenelg River in south-western Victoria, Australia (Figure 1). Under low flow conditions, the estuary extends over 70 km. Although shallow at its mouth, the estuary is around 8 m deep downstream, decreasing gradually to around 4 m at the upstream tidal limit (Nicholson, Jenkins, Sherwood, & Longmore, 2008). It can close seasonally under low flows, with the mouth occasionally artificially opened to alleviate flooding (Glenelg Hopkins Catchment Management Authority, 2006).

Twenty-four juvenile to sub-adult mulloway were captured and tagged between 23/10/2008 and 18/02/2009, and tracked for three years. Tagged fish had a mean (± SD) total length of 622 ± 8 mm, ranging from 501 to 781 mm (Table 1). Four fish were captured by angling, with the remaining fish captured by gill nets (25 m long, 2-m drop with a stretched mesh of 11.25, 12.5 or 15 cm). The gillnets were set in the late afternoon and monitored every 10–20 min so that fish could be removed quickly from the net to minimize capture injury and stress (cf. Sakabe & Lyle, 2010).

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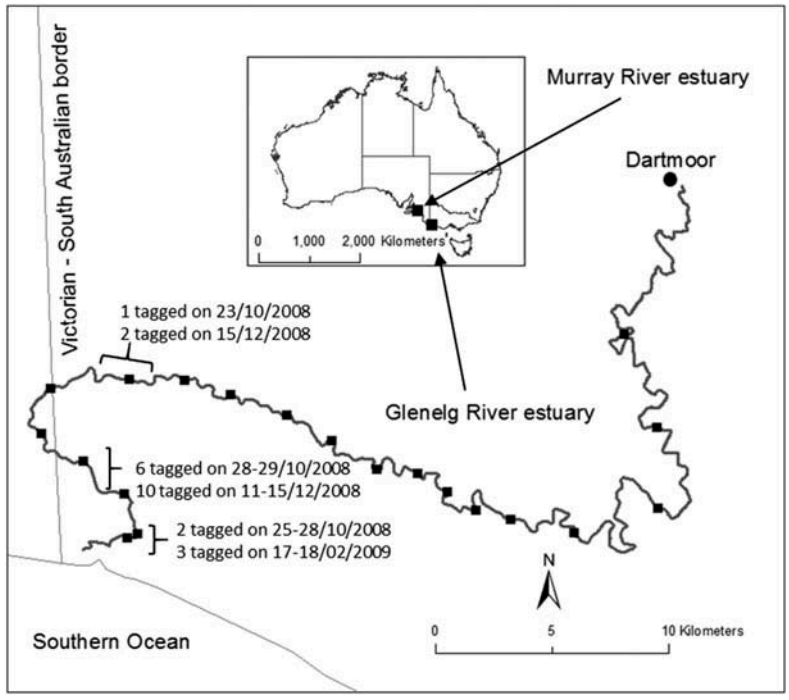

Figure 1. Locations of acoustic receivers in the Glenelg River estuary (black squares) and where mulloway was tagged.

Acoustic tagging of fish followed Koster, Dawson, and Crook (2013). Anaesthetised fish were weighed (nearest g) and measured (total length, mm). Implantation of transmitters generally took 4–5 min and recovery to full consciousness was usually 5–8 min. The individually coded transmitters (V16-4x-069k-1, VEMCO) were 68 mm long, 16 mm wide, weighed 11 g in water, emitted a signal at a random pulse interval of 40 to 120 s, and had an expected battery life of 1000 d. An external dart tag (Hallprint) was also inserted into the muscle surrounding the dorsal fin spine. Information on the dart included an individual tag number, a phone number for reporting the capture of a tagged fish and offered a reward.

VEMCO Model VR2W acoustic receivers were used to monitor individual mulloway movements for up to three years. An array of 20 receivers was deployed throughout the estuary from within 1-km upstream of the estuary mouth to 65 km upstream (Figure 1). As the downstream 600–700 m of the estuary is often very shallow (<0.5 m), the lowest receiver in this study was placed upstream of this shallow water. Distances between receivers were 2–3.5 km, increasing to 7–8 km for the four most upstream receivers. The read-range of the test tags was greater than 400 m.

Daily discharge records were obtained from a gauging station at Dartmoor, just above the tidal limit (Figure 1). Daily observations of the condition of the estuary entrance (open or closed) were obtained from the Glenelg Hopkins Catchment Management Authority. Water temperatures and electrical conductivity were measured using data recorders (Odyssey salinity/Temperature Data Recorders) at every receiver.

To assess relationships of mulloway movement and habitat preferences with different environmental factors (e.g. entrance condition, flows, salinities) in the estuary, Generalised Linear Mixed Models (GLMMs) were intended to be used. However, it soon became clear that the reduced sample sizes caused by heavy angling pressure severely weakened the power of the planned analysis. Therefore, nonparametric analyses (Wilcoxon rank-sum and Kolmogorov–Smirnov tests) had to be

used to determine whether environmental variables differed between days when fish moved or did not.

3. Results and discussion

3.1. Mulloway movement and habitat preferences

During this three-year study, there were only 13 acoustically tagged fish in the system with >100 days' data on movement (Table 1) because heavy angling pressure halved the original sample size (see *Angling pressure*). The available data indicate that mulloway in the Glenelg River estuary spent more time near the mouth than in upstream habitats, although movements of fish were detected up to 58 km upstream (Figure 2). These upstream movements were recorded in December 2008 to May 2009, coinciding with low freshwater inflows and peak salinities (Figure 3).

Thirteen mulloway exited the Glenelg River (Figure 4), with almost 90% of exits between November and January. On the days when these fish left the estuary, discharge was significantly higher (Wilcoxon rank-sum test, P = 0.041). Seven of the 13 fish that exited the estuary re-entered between four and 18 months later. Mulloway did not re-enter the estuary at a consistent time of the year, although five of the seven fish re-entered between June and October (austral winter/spring). One mulloway made multiple exits and entries, leaving four times between August and December and entering twice in May and once each in October and December. This included entering and leaving on the same day on one occasion. As the lowest receiver was not placed at the extreme mouth of the river, other mulloway may have exited and re-entered the estuary within a day without being detected, and daily entry/exits have been recorded in South Africa (Naesje et al., 2012). Four fish that exited the system were detected at the Murray River estuary >450 km away (Figure 1), and exited at similar times of the year (December 2008, November 2009, November 2010 and December 2010). One of these fish was captured by an angler on the beach adjacent to the Murray River estuary, while two returned to the Glenelg River estuary in June or July the year after exiting.

Based on growth rates presented in Ferguson et al. (2014), the predicted sizes of these fishes when they exited the Glenelg River estuary (712, 787, 839 and 900 mm) and predicted sizes at the Murray River estuary (731, 906, 1013 and 1050 mm) match those of mature or near-mature fish. It has been proposed that the ocean near the Murray River estuary is a mulloway breeding area (Ferguson et al., 2008). The results indicate these four fish may have migrated from the Glenelg River estuary to the area around the Murray River estuary for breeding. Furthermore, the timing of detection in the Murray River estuary coincides with the breeding period of spring-summer for this sub-population.

3.2. Angling pressure

During this three-year study, 13 of the 24 tagged mulloway were confirmed as caught and kept by recreational anglers, with recreational anglers phoning in and reporting the fish as captured and kept; another individual fish was phoned in and reported as captured and released. An additional fish went missing between arrays, and it is highly likely this fish was also angled but not reported, as the tag was constantly detected later the same day at a receiver opposite a boat ramp. All fish captured and kept by anglers were caught during the warmer months (7 November to 2 April). Ten fish did not leave the estuary before being captured and kept by recreational anglers (Figure 4), with four of these fishes captured within 100 days of tagging (Figure 5). Recreational anglers captured three fish that left the estuary; one on an ocean beach near the Murray River estuary and two (94 and 167 days) upon returning to the Glenelg River estuary. This intense angling pressure and retention of captured tagged fish highlight the major impact that recreational angling had on the original sample size in this study, severely limiting the intended analyses of movements and habitat preferences of this target species. However, it did allow some assessment of the size of the fish being angled in the Glenelg River estuary.

Table 1. Summary data for acoustically tagged mulloway

Fish Number	Length	Weight	Date tagged	Date captured by recreational angler	Last date detected	No of days detected	Total period tracked	Exit Date	Re-entry Date
1	515	1540	23/10/2008	18/01/2009 [a]	14/12/2009	392	418		
2	704	3298	25/10/2008		15/12/2010	601	782	4/11/2009	27/03/2010
3	501	1312	28/10/2008	2/04/2010 [b]	5/01/2009	69	70		
4	610	1960	28/10/2008	27/12/2009	27/12/2009	163	426	7/01/2009	24/09/2009
5	543	1576	28/10/2008	7/11/2009	6/11/2009	363	375		
6	594	1988	28/10/2008	9/03/2009	8/03/2009	126	132		
7	617	2238	29/10/2008		8/12/2010	483	771	30/12/2009	7/10/2010
8	664	2626	29/10/2008	12/01/2009	12/01/2009	74	76		
9	557	1736	29/10/2008		19/09/2011	740	1056	25/11/2010 (Murray River estuary 24/05/2011)	30/07/2011
10	589	2000	11/12/2008		17/10/2011	534	1041	5/11/2009, (Murray River estuary 29–31/12/2009), 18/10/2011	18/06/2010
11	612	2086	11/12/2008	26/03/2010	26/03/2010	337	471		
12	781	4770	11/12/2008	3/12/2010 [c]	28/12/2008	15	18	28/12/2008 (Murray River estuary 3/12/2010)	
13	598	1782	11/12/2008	18/11/2009	18/11/2009	185	343	8/01/2009	4/06/2009
14	640	2332	12/12/2008	21/02/2009	21/02/2009	36	72	21/02/2009	
15	658	2320	12/12/2008	15/02/2009	14/02/2009	61	65		
16	706	3020	15/12/2008	27/12/2009	26/12/2009	76	377		

(*Continued*)

Table 1. (*Continued*)

Fish Number	Length	Weight	Date tagged	Date captured by recreational angler	Last date detected	No of days detected	Total period tracked	Exit Date	Re-entry Date
17	585	1970	15/12/2008		27/10/2011	32	1047	18/12/2008, 10/09/2010, 14/12/2010, 22/08/2011	18/05/2010, 14/12/2010, 23/05/2011, 10/10/2011
18 [d]	556	1570	15/12/2008		18/12/2008	4	4	18/12/2008	
19 [d]	655	2265	15/12/2008		16/12/2008	2	2	18/12/2008	
20 [d]	583	1916	15/12/2008		17/12/2008	3	3	17/12/2008	
21	656	2644	15/12/2008	24/01/2009	24/01/2009	38	41		
22	653	2510	17/02/2009		11/12/2010	603	662	11/12/2010 (Murray River estuary 11–12/2011, 30/11/2011)	
23	723	3254	17/02/2009	17/12/2009	16/12/2009	283	303		
24	628	2156	18/02/2009		12/11/2009	220	268		

[a]released

[b]transmitter stopped working on 5/01/2009, fish recaptured by a recreational angler on 2/04/2010

[c]recaptured by a recreational angler outside of the Glenelg estuary

[d]not used in the estuarine analysis

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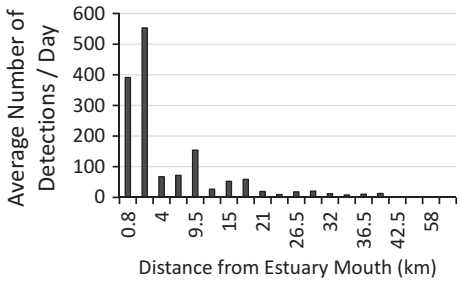

Figure 2. Average number of detections per day at each receiver. Note lower detections at mouth (0.8 km). Although this receiver went missing after a few months, its records were included due to the number of tags available for detections and as it was also an important movement time.

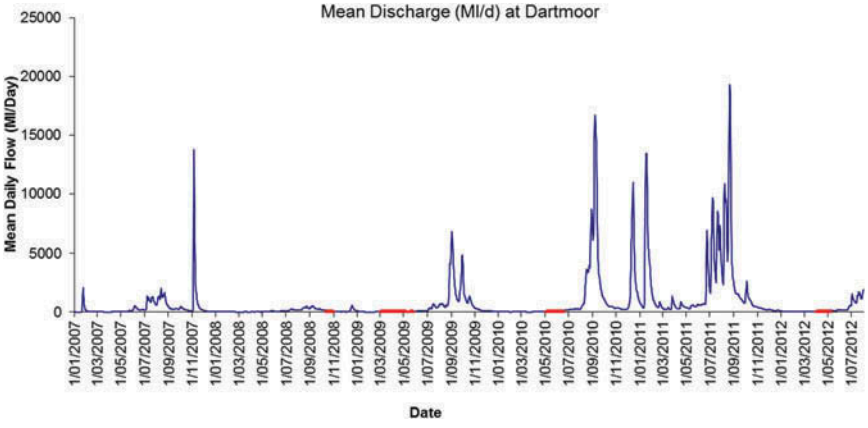

Figure 3. Mean daily discharge at Dartmoor (just upstream of tidal extent) prior to, during and immediately after the study period. Red bars represent periods of estuary mouth closure. Note the estuary was artificially opened on 5 May 2009 and 16 June 2010.

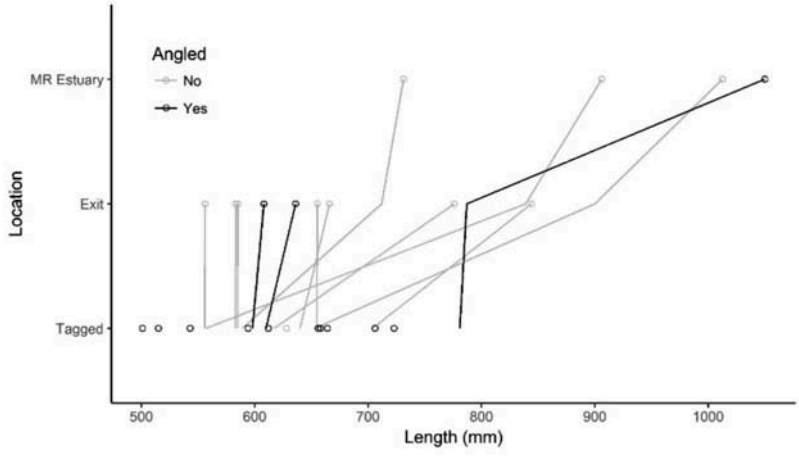

Figure 4. Initial and (for recaptured fish) final total lengths of tagged mulloway in the Glenelg River estuary (Tagged) and whether they were angled, exited the estuary (Exit), and/or were detected at the Murray River Estuary (MR Estuary). Two fish that exited the estuary but did not move to the Murray River estuary were angled upon returning to the Glenelg River estuary.

3.3. Size of fish angled

Based on the growth rates determined by angler-capture lengths compared to lengths at tagging, an estimated growth rate of 11 cm/year was calculated. This is similar to the rate (13.6 cm/year) documented for the Murray River sub-population by Ferguson et al. (2014). There was a propensity for anglers to catch immature mulloway in the 63 to 75-cm range (Figure 6). As the legal size for mulloway is 60 cm in Victoria, the data show that in the Glenelg River estuary, the species is likely to be caught within one year of reaching legal length. Mulloway from the Murray River sub-population reaches maturity at 85 cm for females and

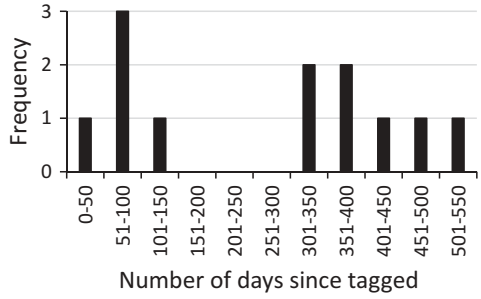

Figure 5. The number of mulloway recaptured by anglers compared to days since tagged.

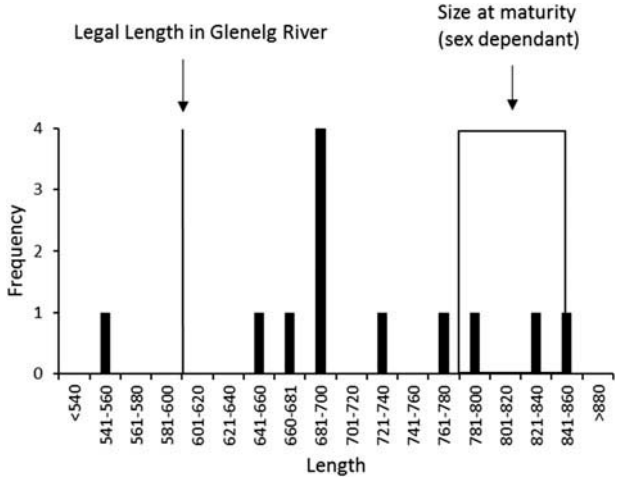

Figure 6. Length-frequency graph of recaptured mulloway in the Glenelg River estuary. Recapture length calculated following Ferguson et al. (2014). Line at 600 m represents legal angling length in Victorian estuaries. The shaded are between 780-850 mm represents size at which this population reaches maturity.

78 cm for males (Ferguson et al., 2014), implying that they are being captured and removed from the population before reaching maturity.

Over 80% of the commercial catch of mulloway in South Australia is taken from the Murray River estuary, with most of these being juvenile or sub-adult fish. The potential impacts of recreational fishing on fish stocks can be great, even rivalling that of commercial fisheries (Cooke & Cowx, 2006). In the Clarence River estuary, New South Wales, recreational catch of mulloway equalled the commercial catch (West & Gordon, 1994), and 78% of mulloway caught in the Clarence River by anglers were below the minimum size (45 cm at the time, with this sub-population maturing at around 50 cm). Mulloway are overfished in New South Wales for females that are immature (Silberschneider, Gray, & Stewart, 2009), and the species is also overfished in South Africa (Griffiths, 1997) and other parts of eastern Australia (Silberschneider et al., 2009). Data from the present study indicate that in the Glenelg River estuary, there is an age- or size-dependency for mulloway to be captured by anglers. This population is also vulnerable to fishing as juveniles in estuarine habitats and as adults in spawning aggregations around the Murray River estuary (Ferguson et al., 2014). A review of the effects of overfishing juveniles in conjunction with reassessing the legal size of mulloway within Victoria is recommended.

3.4. Conclusions and implications

Despite the truncated sample size, the acoustic telemetry study revealed that mulloway in the Glenelg River estuary shows a habitat preference for the downstream end of the estuary, seldom moving further than 50 km upstream except during low flows. Continuity of the sub-population in this estuary with that in the Murray River estuary appears to be maintained by

movements from the Glenelg River estuary to the breeding area in the ocean near the Murray River estuary.

This study also demonstrates the high intensity of angling pressure on mulloway in the Glenelg River estuary, revealing a serious risk of overfishing as juveniles and sub-adults in this estuarine habitat which should prompt a review of legal size. So intense was the angling pressure that over 50% of the tagged fish were captured by recreational anglers. This reduction in sample size severely limited the intended analyses of movement and habitat preference of these species. Although tagged fish have been captured in other telemetry studies, this appears to be the first time it has been documented that anglers capturing and keeping acoustically tagged fish can severely impact the intended analyses. This cautionary tale exemplifies the challenges of telemetric studies of intensively angled fishes in estuaries and other semi-enclosed waters. A key recommendation is that practitioners should inflate their sample size in heavily fished waters to compensate for the impact of angling.

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Competing Interests
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