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Overexploitation causes profound demographic changes to the protandrous hermaphrodite king threadfin (*Polydactylus macrochir*) in Queensland's Gulf of Carpentaria, Australia

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ABSTRACT

Fishing pressure is a significant driver of the demography of exploited fish populations. Here, we examine temporal patterns in the demography of king threadfin (*Polydactylus macrochir*), a large, protandrous teleost, in Queensland's south-eastern Gulf of Carpentaria, Australia, between two periods: 1986–1990 (Period 1) and 2007–2009 (Period 2). Significant age truncation was evident from Period 1 (max age = 14 years, modal age = 5 years) to Period 2 (max age = 8 years, modal age = 3 years). Fish >5 years constituted 58% of the catch in Period 1, and less than 4% of the catch in Period 2. Length and age at sex change differed considerably between periods. In Period 1, the relationships between length and sex ratio and age and sex ratio were best described by a logistic model with 50% of the population changing sex to female at 889 mm fork length and at 6.3 years of age. In Period 2, there were substantially more females in small length and younger age classes with no obvious length or age at which sex change occurred. The predicted mean asymptotic length (L_∞) from the best-fit models of growth was 361 mm greater in Period 1 than in Period 2, while the growth rate (K) was more than twice as high in Period 2 than in Period 1. Fishing mortality during Period 2 was estimated to be 2–3.5 times higher than that of natural mortality (M) and 2.6–5.4 times higher than that of Period 1, depending on the maximum age used to calculate M. No significant trends were evident in total annual rainfall or air temperature in the region over the study period, suggesting the observed changes in demography were not related to contrasting patterns in rainfall or temperature between sampling periods. These results suggest that heavy fishing pressure has likely had a profound effect on the demography of *P. macrochir* in the study region over a period of approximately 20 years, with the use of gillnets resulting in the selective removal of larger, older, female *P. macrochir* and subsequent reductions in age structures and sex change schedules. Accordingly, management intervention is urgently required to reduce fishing pressure and restore the natural demography of the population.

1. Introduction

Globally, fishing pressure has caused significant change in the demography of fish populations (Sinclair et al., 2002; Hidalgo et al., 2009; Silberschneider et al., 2009; van Walraven et al., 2010; Stewart, 2011). Size-selective fishing gear such as gillnets generally favor the survival of smaller individuals, leading to overall truncations in length and age structures and/or decreases in length-at-age, with subsequent alterations in maturity profiles and overall reproductive potential (Ricker, 1981; Silberschneider et al., 2009; Chuwen et al., 2011). Conversely, such practices may also result in reductions in population density, resulting in lower levels of competition and increased availability of food, leading to faster growth and subsequent increases in length-at-age (Sinclair et al., 2002; Hidalgo et al., 2009). Hermaphroditic fishes are particularly susceptible to over-fishing since exploitation is often size- and, therefore, sex-selective, and consequently the impact of any fishing on a sex-changing species will depend on the type of hermaphroditism exhibited, their reproductive schedules

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(including size- and age-at-maturity and sex change), and any size regulations for retention like minimum or maximum legal lengths. In protandrous hermaphrodites (i.e. those species that change sex from males to females during their lifecycle), unsustainable levels of fishing pressure can affect the reproductive potential and population replenishment of a population in two ways: 1) through selective harvesting of larger, mostly female individuals, resulting in egg limitation, and 2) subsequent decreases in the length and age at which sex change occurs, leading to reductions in total fecundity due to allometric differences in egg production and production of offspring with reduced survivorship relative to those of larger, older, individuals (Trippel et al., 1997; Marteinsdottir and Steinarsson, 1998; Platten et al., 2002; Hawkins and Roberts, 2003; Gotz et al., 2008).

King threadfin, *Polydactylus macrochir* Günther 1867 (Polynemidae), is a large, protandrous teleost that supports valuable commercial, recreational and subsistence fisheries in tropical and subtropical estuaries and associated turbid coastal waters of northern Australia, southern Papua New Guinea and Irian Jaya (Motomura et al., 2000). *Polydactylus macrochir* can live for at least 22 years and reach an estimated maximum attainable size of 40 kg and 170 cm fork length (Kailola et al., 1993; Moore et al., 2011). Evidence for sequential protandry in the species has been observed from macroscopic and histological examination of gonads, with variation in the length and ages at which sex change occurs evident among populations (Pember et al., 2005; Moore et al., 2011, 2012a).

Polydactylus macrochir forms an important component of northern Australia's commercial inshore net fisheries, second in importance to only the iconic barramundi, *Lates calcarifer*. Historically, a large proportion of Australia's *P. macrochir* catch has come from Queensland's Gulf of Carpentaria (GoC) waters, where the majority of the catch is taken through the inshore commercial net fishery operatuing in the south-east of the Gulf, with minor catches taken by the recreational, indigenous and charter fishing sectors (DEEDI, 2012). In 2010, 377 t of *P. macrochir* were harvested through the inshore commercial net fishery in Queensland's GoC, equating to approximately 72% of the state's total *P. macrochir* commercial catch (DEEDI, 2012; DAF, 2015). Recent investigations of otolith isotopes, mitochondrial DNA and parasite markers suggests *P. macrochir* in Queensland's GoC represent a single stock, separate to that on Queensland's east coast and the western GoC (Newman et al., 2010; Horne et al., 2012; Moore et al., 2012b). Tagging data and otolith elemental profiles indicate that fish may reside in association with individual GoC estuaries for months to years (Welch et al., 2010; Moore and Simpfendorfer, 2014).

Management of the *P. macrochir* stock in Queensland's GoC waters is based on both input and output controls. In 1981 a series of management interventions were implemented, largely due to concerns over apparent declines in *L. calcarifer* stocks in the region. Most notably, these included restrictions on total net length and minimum mesh size (to 150 mm) and a seasonal closure from November-January during which all set-netting was banned (Roelofs, 2003). A compulsory daily commercial logbook program for Queensland fisheries was also implemented in 1981, with logbooks updated to their current form in 1988 (Roelofs, 2003). In 1996, further restrictions were implemented, again mainly to conserve *L. calcarifer* stocks, including an increase in the minimum legal net mesh size to 162.5 mm stretched mesh diameter, and an extension of the seasonal closure to October-January. In 1999, the minimum legal size for *P. macrochir* caught in Queensland's GoC waters was increased from 400 mm total length (*TL*) to 600 mm *TL*, and a recreational possession limit of 5 individuals was introduced (Roelofs, 2003). Assessment of the *P. macrochir* fishery in Queensland's GoC has historically been based on a performance measure approach, whereby a decline by more than 30% in commercial catch rates (standardised to kg per day) over a three year period triggers a review of management measures for the fishery (DEEDI, 2012). Catches and catch rates have generally been stable since the inception of the logbook program up until 2010; however recent reporting suggests commercial catches and catch rates in the region have declined substantially to near historically low levels from 2011 onwards (Fig. 1) (DEEDI, 2012; DAF, 2015).

Table 1
Data types available from the two collection programs targeting *Polydactylus macrochir* in Queensland's south-eastern Gulf of Carpentaria.

Data available	Sampling period	
No. samples including	Period 1	Period 2
Length data	1268	356
Length and sex data	1268	354
Length and age data	113	356
Length, sex and age data	28	354

The recent declines in catches and catch rates mirror those in the early to mid-1990s when catch rates were at then historically low levels (Fig. 1). Large declines in catch rates may reflect declines in stock size and/or shifts in population structure. In a preliminary analysis, Moore et al. (2012a) observed considerable age truncation and a greater proportion of small, young females in samples from Queensland's GoC compared to elsewhere across the species' Australian distribution. Here, we assess the temporal stability in demography of *P. macrochir* within Queensland's GoC from two collection periods separated by approximately 20 years. In particular, we explore changes in length and age structures, length and age at sex change, growth, and mortality estimates. As the biology of fishes is typically strongly influenced by the environment in which they reside, and in particular freshwater flow and water temperature (Robertson et al., 2005; Halliday et al., 2008; Morrongiello et al., 2014), temporal patterns in sea surface and air temperatures in the region are also examined. Finally, management and monitoring scenarios for this species, and for protandrous hermaphrodites in general, are discussed.

2. Methods

2.1. Data collection

Demographic data used in this study were obtained from two data collection programs in Queensland's south-eastern GoC spaced approximately 20 years apart: 1986–1990 ('Period 1') and 2007–2009 ('Period 2', see Welch et al., 2010) (Table 1). Samples from Period 1 were collected via fishery-dependent sampling from fishers using gillnets of 150 mm, 162.5 mm and 178 mm stretched mesh diameter from the Flinders and Norman Rivers (Fig. 2). Data types available for Period 1 varied widely with respect to sample sizes (Table 1), with otolith material for ageing purposes collected on an opportunistic basis while trying to ensure representativeness. Samples from Period 2 were collected via fishery-dependent sampling from fishers under state government permits that allowed retention of undersized fish to obtain a more complete size range from the population for biological studies. Sampling in Period 2 used gillnets of 162.5 mm stretched mesh diameter and samples were obtained from the Albert, Flinders and Staaten Rivers, Morning Inlet and Spring Creek (Fig. 2). Fork length (*FL*) and total length (*TL*) were measured to the nearest 5 mm in Period 1 and nearest 1 mm in Period 2 for each fish, unless damaged. Sex of samples from both periods was determined from a macroscopic examination of the gonads, considered to provide a comparable estimation of sex to histological examination (Pember et al., 2005). Sagittal otoliths (hereafter referred to as otoliths) were removed, cleaned, dried and stored in plastic vials for later ageing which followed