Spatial Ecology and Sex Ratios in Gag Grouper, *Mycteroperca microlepis*: Implications for Management

Ecologia Espaciales y la Proporcion de Sexos en la Gag Grouper, *Mycteroperca microlepis*: Implicaciones para la Gestion

L'ecologie Spatiales et des Rapports Sexuels dans Gag Grouper *Mycteroperca microlepis*: Implications pour la Gestion

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EXTENDED ABSTRACT

Introduction

Reproductive resilience has been defined as the capacity of a population to maintain the level of reproductive success needed to result in long-term population stability despite disturbances. Although reproductive success is tightly coupled with adult abundance and fecundity in many terrestrial animals, it may play less of a role in marine exploited fish which typically produce millions of pelagic eggs (Lowerre-Barbieri et al. 2016). In fisheries science, reproductive potential is the annual variation in a stock's ability to produce viable eggs and larvae that may eventually recruit to the adult population or fishery (Trippel 1999) and thus a measure of reproductive success. Reproductive potential is traditionally measured as female spawning stock biomass (SSB) or total egg production (TEP), but there is growing recognition of the need to integrate a more eco-evolutionary perspective (Mangel et al. 2013, Kindsvater et al. 2016) and address other measures such as: spatial, temporal or demographic trends in reproductive value and sperm limitation in protogynous hermaphrodites (SEDAR 2015).

Gag grouper (*Mycteroperca microlepis*) support extensive commercial and recreational fisheries, especially along the Gulf coast of Florida, where most gag are landed (Schirripa and Goodyear 1994). Because gag have a sequential protogynous hermaphroditic gender system, all males must recruit from the mature female population (Koenig et al. 1996). This, in combination with highly-specific depth and habitat preferences, slow growth, and presumed male site fidelity contributes to their high susceptibility to overexploitation (Heppell et al. 2006). Gag spawn at the shelf edge and produce pelagic eggs. Pelagic larval duration is from 30 to 60 d, after which gag settle in estuaries (Fitzhugh et al. 2005). The arrival time and duration of juveniles within estuaries varies with latitude, and estuarine juvenile abundance varies temporally, with peaks in juvenile recruitment historically occurring every 2 to 4 years (Switzer et al. 2012). Gag spawning aggregations form from December to May, with peak spawning in February and March (Hood and Schlieder, 1992). Evidence suggests males may remain at the shelf edge year-round, whereas females return to nearshore reefs after spawning (Coleman et al. 1996).

The spatial ecology of gag (Figure 1), although not yet fully understood, affects our ability to accurately estimate sex ratio and drivers of reproductive success. Sex allocation theory predicts adult sex ratios should be those resulting in the greatest reproductive success, with maturation schedules optimizing fitness benefits. In protogynous fishes, males exhibit delayed maturation, predicted to evolve when male competition is important to the mating system (Stearns 1992). Gag grouper exhibit spatial ecology suggestive of a lek mating system, with males remaining on the spawning grounds and females moving to and from the area. In contrast, another important protogynous species, the red grouper, *Epinephelus morio,* exhibits greater male dispersion. Life history theory predicts the gag grouper mating strategy should not produce young males, or very rarely, whereas they should be more common in red grouper and these with important implications for fisheries management.

Methods

Data from the first year of a three-year study was collected at deep shelf-edge reefs along the west Florida shelf from December through May. Three regions, with varying management regimes, were sampled with hook and line and video:

i) Madison Swanson, which is a marine protected area where bottom fishing has been prohibited since 2000,
ii) An unprotected area to the northeast of Madison Swanson with similar habitat, and

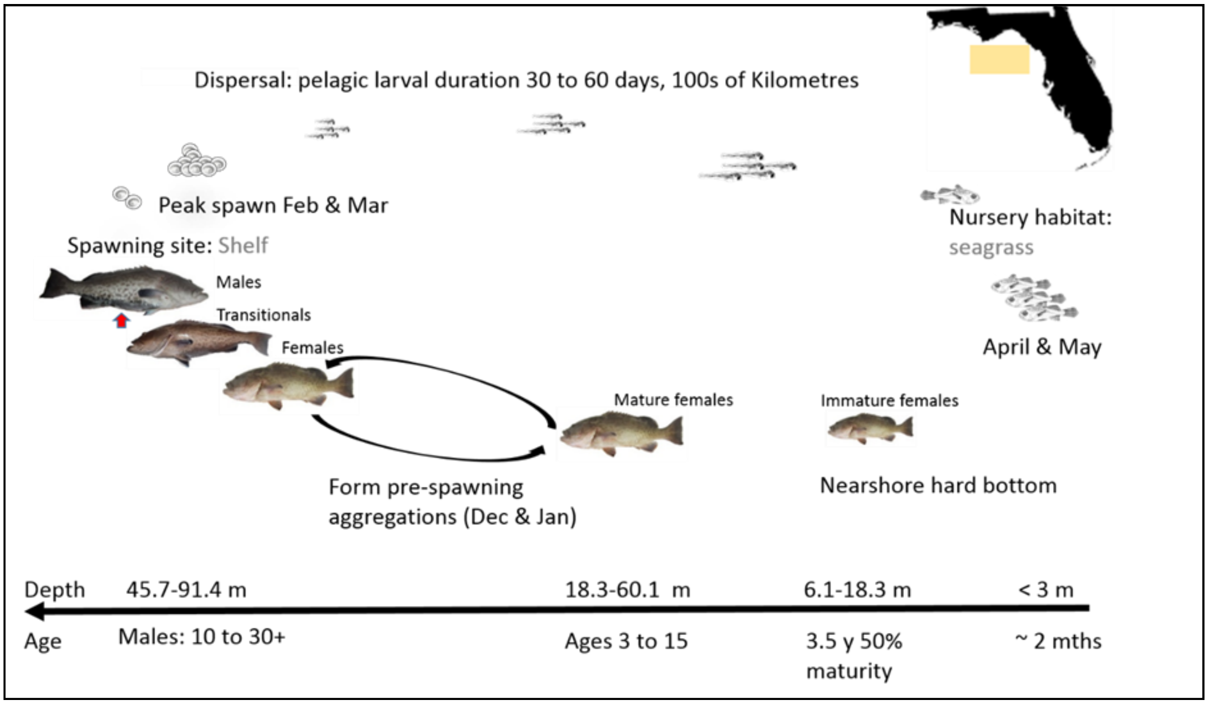

Figure 1. Current understanding of the gag grouper life cycle and spatial ecology on the west Florida

iii) The northern part of the Edges, which is closed to bottom fishing from January 1 – April 30.

Effort (time spent fishing) was tracked and tackle and methods standardized over all sampling events. In addition, prior to fishing, video data was collected for twenty minutes in each zone from a camera array with three go pro cameras to ensure a 360^0 view. Captured fish were assessed for hook placement and barotrauma effects and measured (standard and total length, mm; total weight, kg) and photographed to assess external pigment patterns when first landed and after death. Gonads were assessed macroscopically and histologically (Brown-Peterson et al. 2011). The proportion of males sampled was compared across regions, as well as by month within the MPA. The age at 50% male (A_{50}) was estimated for the MPA using logistic regression. Relative condition was estimated as weight of the individual fish divided by the predicted length-specific mean weight (Blackwell et al. 2000). Because few males were collected in peak spawning months, potentially due to mating behavior impacting foraging, mean condition of males collected in pre- and post- spawning months were compared by t-test.

RESULTS AND DISCUSSION

Most captured fish (93%, n = 245) and all males came from the MPA. The population in the reserve was 9.3% male and 0.9% transitional (n = 226). However, the proportion of males varied significantly by month ($X^2 = 19.91$, $p = 0.03$, $DF = 10$), ranging from 19% in December to 0% male in March. The low proportion of males sampled during peak spawning agrees with other studies (SEDAR 33) and indicates the difficulty in accurately estimating this parameter. A number of factors could affect male catchability, with decreased foraging during peak spawning a potential factor as male condition was significantly lower in post-spawning months than pre-spawning months (t-test, n = 21, $p = 0.012$). The observed proportion of males at age, in turn drives estimates of A_{50}, which we estimated for the MPA to be 13 years. This is older than that reported for the Gulf stock (10.9 years) and although potentially an artifact of small sample size, it exemplifies the importance of this parameter and choice of reproductive potential measure. Using the stock assessment model (SEDAR 2014) to compare results with an A_{50} of 10 versus 13 resulted in greater female SSB and consequently TEP, but fewer males in the population (Figure 2). Our results, as well as the relatively invariant gag A_{50} with significant declines in male numbers (~20% in the 1970s to ~5% or less now), and very low numbers of transitionals, suggests either that proportion male on the spawning grounds is not the main driver of transition or that we do not yet understand the spatial ecology of males and transitionals and consequently their vulnerability to fishing.

Understanding productivity in a species like gag grouper, with a complex life history, necessitates integrative science and drawing on a wide range of expertise. To try to meet this need we are developing a working group with stock assessment scientists, experts in gag biology, physiology, lipid analysis and genetics.

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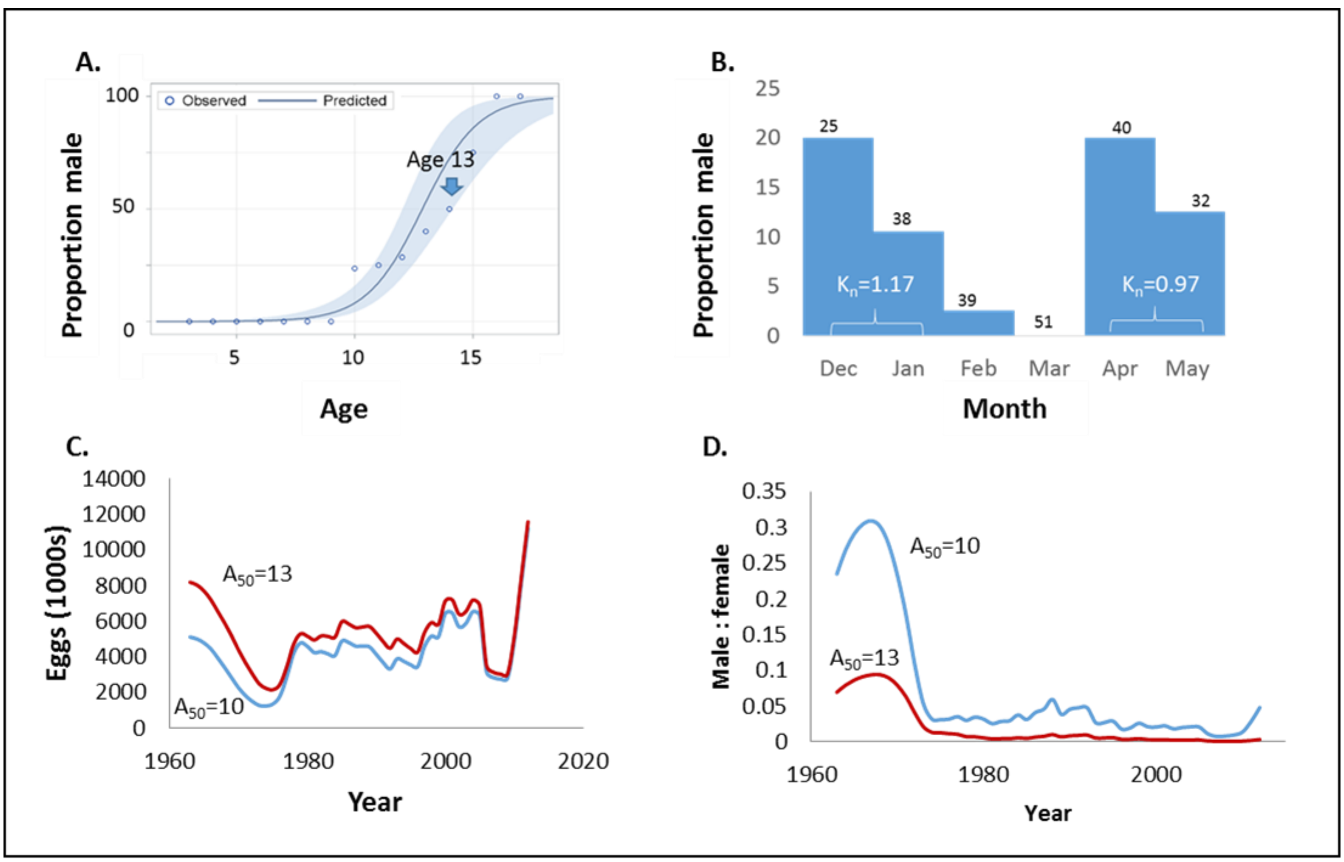

Figure 2. A. Age at 50% male (A_{50}) was 13 years, based on samples from the Madison Swanson MPA (n=226); (B) proportion of males sampled in the MPA by month and mean male relative condition factor (Kn) for pre-spawning months (December and January) vs post-spawning months (April and May); C. The number of eggs predicted by the stock assessment model with A_{50} of 13 (red) versus 10 (blue); and D. The male to female sex ratio with A_{50} of 13 (red) versus 10 (blue).