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Importance of considering reproductive characteristics for management of marine fisheries

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Original Article

Abstract

Status of fish stocks in relation to fishing may differ from one area to another, but there is a general consensus that several fish stocks need effective management measures by taking into consideration different indicators of stock status. Through a review of literature, this paper shows the importance of integrating the reproductive characteristics into the plan for management and conservation of marine fisheries as well as ecosystems. Overexploited fishes display symptoms of (i) advancements in age and/or size at sexual maturity and (ii) reduction in fecundity in gonochoristic (bisexual) fishes. Protogynic hermaphroditic fishes show symptoms of advancement in sex/age at sex change and decrease in Reproductive Life Span (RLS). Consequent to these changes in reproductive characteristics, the Spawning Stock Biomass (SSB) will decrease leading to depletion and collapse of a stock or species of fishes. In response to advancement in Age at Sexual Maturity (ASM) and/or Size at Sexual Maturity (SSM), the depleted stock/species may display one of the following symptoms: (a) decrease in fecundity, as in European hake *Meruluccius meruluccius*, or (b) decrease in egg size, as in *Gadus morhua* or (c) both decrease in fecundity and egg size, as in roughy *Hoplostethus atlanticus*. The protogynics economize male and sperm availability by behavioral acts like spawning aggregation; however, the longer residency of such spawning aggregation in a particular site increases the vulnerability of reproductively active parents. Analyses of limited publications show that (i) overexploitation reduces not only male biomass but also female biomass and (ii) reduction in RLS to 50% in female e.g. *Epinephelus niveatus* and 33% in male e.g. *Pagrus pagrus* through precocious sexual maturity and sex change.

Keywords: *Overexploitation, sexual maturity, fecundity, sex change, egg size.*

Introduction

Fisheries constitute one of the most important natural resources for humanity and any reduction in their well-being and ability to propagate as a result of overexploitation may have significant socio-economic consequences. FAO (2012) has reported that out of 90 metric tonnes (mt) captured world over, about 78 and 12 mt arise from marine and freshwater fisheries, respectively. Fisheries provide not only food but also gainful employment. For example, fisheries provide employment for over a million people in India (CMFRI, 2012). However, annual fishing capacity ranges from just 2-3 tonnes (t) for an Asian fisher to 7 to 8 t for a fisher in Europe and North America. Understandably, overexploitation of marine fishery resources, especially by the developed countries has led to almost total collapse (99.9%) of the Atlantic cod (Hutchins and Reynolds, 2004). FAO (2012) lists nine depleted fish species that are beyond recovery; these fishes are mostly known from developed countries (Table 1). The status of fish stocks in world oceans are at different levels of exploitation. For example, FAO (2010) has reported that pelagic and demersal fishes remain underexploited along the northeast coast of India but overexploited along southeast coast. However, it has been more recently recognized that the fishery resources in the Asian countries are also on the verge of being overexploited. For example, Vivekanandan (2013a, b, 2014) has brought to light that the threadfin bream *Nemipterus japonicus* is beginning to suffer overexploitation in the southwest Bay of Bengal. Hence the need for management of marine fisheries has become obvious.

Table 1. Overexploited species (source: FAO, 2012)

Species	Main fishing countries
Gadus morhua	Canada, USA, Greenland
Melanogrammus aeglefinus	Canada, USA
Petrus rupestris	South Africa
Atracloscion aequidens	South Africa
Clupeonella cultriventris	Russia, Ukraine
Alosa pontica	Bulgaria
Thunnus thunnus	France, Italy, Turkey
T. maccoyii	Japan, Taiwan, South Africa
Chaenocephalus gunnari	United Kingdom, S. Korea
Nototheniidae	United Kingdom

Signals of overexploitation

Depletion of a commercial fish stock or species is recognized by fisheries managers by (i) drop in commercial landings, (ii) reduction in catch-per-unit effort (CPUE), and (iii) mean size (Table 2). The CPUE of the overexploited red porgy *Pagrus pagrus*, an important segment of the commercial fisheries of South Atlantic Bight, drastically declined from 11 porgy/trap/hr in 1980 to < 2 porgy/trap/hr in 2004 (Fig. 1). Table 2 lists changes in features of commercial landings of selected overexploited fishes. Fisheries management takes into consideration one or more of these features of stock/species as indicator(s) to assess the level of overexploitation. In addition to those features listed in Table 2, the overexploited fishes also display features like advancements in age and/or size at sexual maturity; reductions in fecundity of gonochoristic (bisexual) fishes and decrease in Reproductive Life Span (RLS) by female to male sex change in protogynic hermaphroditic fishes. Estimation of some of these reproductive characteristics may trace the pathway through which the Spawning Stock Biomass (SSB) is altered leading to depletion and collapse of a fish stock or species. An understanding on the combination of the features on commercial landings and reproductive characteristics may facilitate better management of marine fisheries.

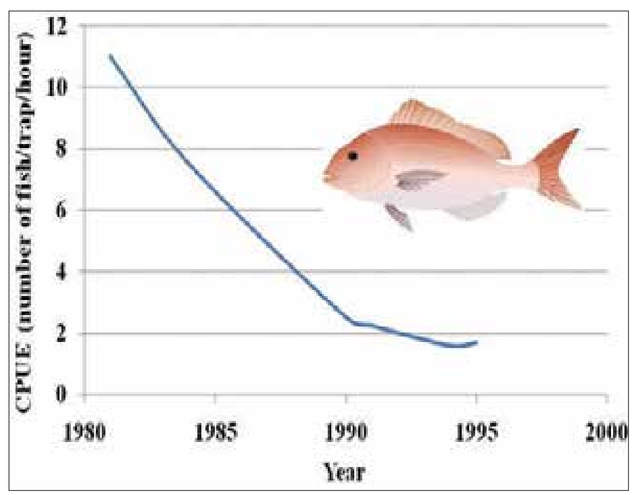

Fig. 1. Commercial landings of red porgy *Pagrus pagrus* as a function of catch per unit effort (source: Harris and McGovern, 1997, modified).

Table 2 Changes in reproductive parameters in the commercial landings of overexploited protogynics during the period from 1972 to 2002 in southeastern United States

Features	Reported changes
Pagrus pagrus (Harris and McGovern, 1997, Vaughan and Prager, 2002)	
Fishing mortality (F)	Increased from 0.25 in 1972 to 0.8 in 1998
Commercial landings (t)	Reduced from 1.5 mt in 1971 to 0.2 mt in 1995; number decreased from 200,000 during 1970s to 100,000 after 1988
Mean size landed (kg/fish)	Decreased from 1.1 kg in 1972 to 0.7 kg in 1998
Largest size captured (cm)	57.5 in 1980s
Catch effort	
(i) (no/trap/hr)	Decreased from 10 in 1980 to 1.5 in 1995
(ii) (no/trap)	Decreased from 0.8 in 1992 to 0.1 in 1998
SSB (t)	Decreased from 2500 in 1972 to 500 in 1998
Epinephelus niveatus (Wyanski et al., 2002)	
Landings in South Carolina (t)	Reduced from 130 in 1982 to 40 in 1996
Mean size landed (cm)	65-80 during 1970; 50-60 in the mid 1990s
Captured by snapper reeds	
(i) largest size landed (cm)	105 in 1979-1985; 98 in 1993-1994
(ii) oldest landed (age)	22 y in 1979-1985; 18 y in 1993-1994

Advancement of age at sexual maturity (ASM) reduces the scope for storing adequate nutrients to meet the cost of vitellogenesis, whereas size at sexual maturity (SSM) may reduce the space in the body cavity to accommodate the ripening ovaries. The response of fish reproduction to overfishing have been studied both from temperate and tropical fishes. The ASM of the Northeast Arctic cod advanced from 10 year (y) in 1940 to 7 y in 2000 and SSM from 100 cm to 75 cm. Advancement of sexual maturity (ASM), say, from nine months during 1978-1981 to eight months during 2002-2005 was noticed in the threadfin bream *Nemipterus japonicus* off Chennai (southeast coast of India) reduced 9 % of the time window for storage of adequate nutrients to meet the cost of vitellogenesis. SSM of *N. japonicus* also decreased from 38 g to 28 g, i.e. at the rate of 0.4 g/y and thereby reduced the space in the body cavity.

Alternative responses

With advancement of ASM and/or SSM, a fish may opt either to or reduce both the number and size of eggs, or reduce the egg number alone or even reduce the egg size alone. Unfortunately, relevant information on the options of the depleted fishes listed in Table 1 is not available. However, available information indicates that in response to ASM/SSM, the overexploited stock/species may either opt to (i) reduce fecundity, (ii) egg size or (iii) both fecundity and egg size (Table 3). As a consequence of advancing SSM in *Hoplostethus atlanticus*, a pelagic spawner with determinate fecundity, there was 25% reduction in relative fecundity (RF) and 22% reduction in egg size (Minto and Nolan, 2006). With reduction in 12% body weight in SSM of *Meruluccius merluccius*, an asynchronous income (food supply dependent breeder, see also Pandian, 2013) breeding pelagic spawner with indeterminate fecundity (Pandian, 2013), the RF decreased from 187 eggs/g ovary-free fish in 1995 to 133 eggs/g in 2004. The values for specific fecundity (DEP), which ranged between 8.1 and 14.1 eggs/g (ovary-free) body weight during 1995-1998 decreased to 4.0-5.0 eggs/g during 2001-2004 (Murua *et al*., 2010). On consultation, H. Murua (*pers. commu.*) has kindly informed that the egg size may not have undergone any change. Due to overfishing between 1971 and 2004, the sexual maturity advanced and consequently gonado-somatic index reduced in the Peruvian hake *M. gayi* (Ballon *et al*., 2008). Considering all the four size groups (15, 19, 23 and 26 cm TL) of the threadfin bream *N. japonicus* subjected to fishing pressure in southwest Bay of Bengal, Vivekanandan (2013a) found that RF remained almost equal (303-319 eggs/g fish) during the year 1979-2004 whereas, the egg size decreased from 0.12 mg in 1979 to 0.10 mg in 2004. However, the absolute fecundity decreased, as the SSM decreased from 38 g to 28 g. Vivekanandan (2013a) also showed that the condition factor, an index of nutrient reserves in the body to meet the cost of vitellogenesis, also decreased in depleted fishes; for instance, it decreased in *N. japonicus* from 0.175 in 1978 to 0.165 in 2005. In the Chinese anchovy *Coilia mystus*, the egg size decreased from 1.4 mg in 1979 to 1.1 mg in 2007 but its RF increased from 712 eggs to 871 eggs in 2007 (He *et al*., 2011). In the northern cooler waters, the oocytes size of the cod, a low capital pelagic spawner with determinate fecundity, decreased by 6.7%, i.e. from 646 μm in 1986 to 603 μm in 2006 for the Barents Sea stock and by 13.6%, i.e. from 618 μm in 1995 to 534 μm in 2000 for the colder Islandic stock. Apparently, the northern stock is more fragile and suffers larger decrease in oocyte size more rapidly

Table 3 Different types of response in egg number and/or size of overexploited fishes

Reduction in fecundity only (Murua *et al*., 2010)	
Meruluccius meruluccius Cold temperate, Large, Indeterminate income breeder, Hydrated pelagic eggs.	In the Bay of Biscay, RF of the European Lake decreased 187 eggs/g ovary free fish in 1995 to 133 eggs/g in 2004, in response to 12% decrease in size at sexual maturity
Reduction in egg size (Thorsen *et al*., 2010)	
Gadus morhua Cold temperate, > 8 ys life span, Determinate low capital breeder, Hydrated pelagic eggs	Egg size of the European cod decreased from 618 μm in diameter during 1995 to 534 μm in 2000.
Reductions in relative fecundity and egg size (Minto and Nolan *et al*., (2006)	
Hoplostethus atlanticus Cold temperate, Long life span of > 180 y, Determinate fecundity,Hydrated pelagic eggs	Egg size of Atlantic orange roughly decreased from 33 μg at less overexploited Porcupine Bank stock to 27 μg at relatively more overexploited Cook Canyan stock. RF also decreased from 33 eggs/g to 27 eggs/g in these stocks

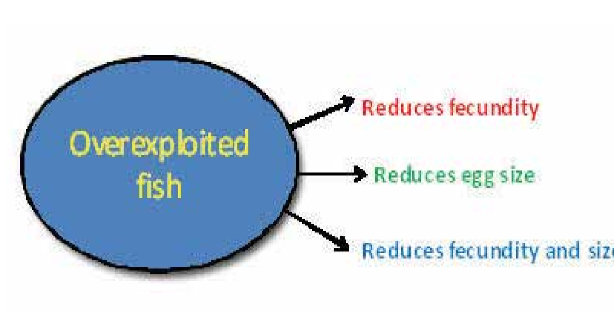

Fig. 2. The three options chosen by overexploited stock/species in response to ASM and SSM.

than that of Barents Sea. However, the annual fecundity of the Barents Sea cod stock remained at around 2 million eggs from 1986 to 2006 (Thorsen *et al*., 2010). In fact, Kraus *et al*. (2000) reported an increase in RF of Baltic cod from 640/g fish in 1987 to 850/g fish in 1996. Clearly, in response to the decrease in age and size at sexual maturity, the egg size decreased but not the egg number in *Gadus morhua*. To an increase in fishing pressure, *H. atlanticus* responded by reducing both the number and size of eggs, *M. merluccius* by reducing fecundity and *N. japonicus*, *C. mystus* and *G. morhua* by reducing the egg size and in the last two species by increasing RF also. However, there is a need for more detailed studies to make any generalization, as the stocks of these depleted fishes are not subjected to the same level of overexploitation. Nevertheless, overexploitation decreases the reproductive potential of a stock or species (i) by reducing the SSB, (ii) reducing age diversity, (iii) advancing ASM and/ or SSM and thereby (iv) fecundity (Pandian, 2014). To cite an example, the SSB of the overexploited Baltic cod decreased from 50,000 females in 1970 to 18,000 in 2008, and in turn, the recruitment from 200,000 in 1971 to 75,000 in 2009. Some of these negative effects of overexploitation on reproductive parameters of gonochoristic fishes are summarized in Table 2.

In female to male sex changing protogynics, the male ratio ranges from 0.06 in *Mycteroperca bonaci* to 0.37 in *Epinephelus akaara*. Within a species like the black grouper *M. bonaci*, there are 15 females for every male in Florida, 30 in Cuba and 77 in Mexico. These location and species specific differences in male ratios of protogynics strongly emphasize the need for accumulation of data on reproductive characteristics and consider them while devising management plans for fisheries and ecosystem management.

In protogynic stocks, selective fishing of large male members was earlier considered to impose sperm limitation, as a required number (> 6,000/egg) of sperm to fertilize an egg may not be available. However, spawning aggregation, an adaptive behaviuor common among protogynics, neutralizes the sperm limitation but ensures sperm economization by reducing sperm requirement to 863/egg (Pandian, 2014). Yet, the protogynics suffer from Reproductive Life Span (RLS) due to advanced sexual maturity and precocious sex change. For example, the RLS of a female snowy grouper *Epinephelus niveatus* is reduced from 8.4 yr^{-1} in 1980s to 4.4 yr^{-1} in 1990s, i.e. 50 % reduction in RLS (Wyanski *et al*., 1998, Pandian, 2014). The RLS of a male red porgy *Pagrus pagrus* is reduced by 33% (Harris and McGovern, 1997, Pandian, 2014). The response of gonochoric and protogynous fishes to overexploitation shows the importance of considering the reproductive characteristics for management of marine fisheries and ecosystems.

References

Ballon, M., C.Wosnitza-Mendo, R.Guevara-Carrasco and A.Bertrand. 2008. The impact of overfishing and El-Nino on the condition factor and reproductive success of Peruvian hake *Meruluccius gayi, Prog. Oceanogr.*, 79 : 307

CMFRI, 2012. Marine Fisheries Census 2010. Part I. India. Central Marine Fisheries Research Institute, Kochi, 179 pp.

FAO, 2010. General Situation of World Fish Stocks. United Nation Food and Agriculture Organization, Rome p. 113

FAO, 2012. The State of World Fisheries and Aquaculture in Asia Pacific. FAO, Rome 230pp.

Harris, P. J. and J. C. McGovern. 1997. Changes in the life history of red porgy *Pagrus pagrus* from the south eastern United States 1972-1994. *Fish. Bull.*, 95: 732-747

He, W-P, Y-X. Li and M. Liu. 2011. Reproductive biology of *Coilia mystus* (Linnaeus) from the Yangtze Estuary, China responses to overexploitation. *J. Appl. Ichthyol.*, 27 : 1197-1202

Hutchins, J. A. and J. D Reynolds. 2004. Marine fish population collapses: Consequences for recovery and extinction risk. *Bioscience*, 54: 297-309

Kraus, G., K. Muller, K. Trella and F. W. Koster. 2000. Fecundity of Baltic cod: temporal and spatial variation. *J. Fish Biol.*, 56: 1327-1341

Minto, C. and C.P. Nolan. 2006. Fecundity and maturity of orange roughy (*Hoplostethus atlanticus* Collet 1889) on Porcupine Bank, Northeast Atlantic. *Env. Biol. Fish*, 77: 39-50

Murua, H. L. Ibaibarriage, P. Alvarez Santos, M. Korta, M. Santurtun, and L. Motos, 2010. The daily egg production method: A valid tool for application of European hake in the Bay of Biscay. *Fish. Res.*, 104: 100-110

Pandian, T.J. 2013. Endocrine Sex Differentiation in Fish. CRC Press, Boca Raton, USA, 302pp

Pandian, T. J. 2014. Environmental Sex Differentiation in Fish. CRC Press, Boca Raton, USA, (in press)

Thorsen, A., P. R. Witthames, G. Marteinsdotir *et al*. 2010. Fecundity and growth of Atlantic cod (*Gadus morhua*) along a latitudinal gradient. *Fish. Res.*, 104 : 45-55

Vaughan, D. S. and M. H. Prager. 2002. Severe decline in abundance of the red porgy (*Pagrus pagrus*) population off the southeastern United States. *Fish. Bull.*, 100: 351-375

Vivekanandan, E. 2013a. Climate change: Challenging the sustainability of marine fisheries and ecosystems. *J. Aquat. Biol. Fish.*, 1:58-71

Vivekanandan, E. 2013b. Sea water warming coincides with shift in the spawning season of a tropical bream in the southwest Bay of Bengal. *Rev. Fish Biol. Fish.*, (in press)

Vivekanandan, E. 2014. Precocious maturity and variations in reproduction of threadfin bream *Nemipterus japonicus* southwest Bay of Bengal. Sexuality, *Early Dev. Aq. Org*. (Communicated)

Wyanski, D. M., D. B. White, and C. A. Barans. 2000. Growth, population age structure and aspects of the reproductive biology of snowy grouper *Epinephelus niveatus*, off North Carolina and South Carolina. *Fish. Bull.*, 98 : 199-218