Western Indian Ocean J. Mar. Sci. Vol. 13. No. 2, pp. 163 - 175, 2014

The Distribution, Biological Characteristics and Vulnerability of the Giant Sea Catfish, *Arius thalassinus* (Rüppell, 1837), to Fishing at Mafia Island, Tanzania

Albogast T. Kamukuru and Rashid A. Tamatamah

Department of Aquatic Sciences and Fisheries, University of Dar es Salaam, PO Box 35064, Dar es Salaam, Tanzania.

Keywords: *Arius thalassinus,* reproduction, vulnerability, artisanal fisheries, Rufiji Delta, western Indian Ocean

Abstract — The distribution and some biological characteristics of commercially important giant sea catfish, *Arius thalassinus* (Rüppell, 1837) were studied at Mafia Island. Artisanal fishing catches were sampled, caught mainly with longlines, shark nets and ring nets. These yielded a total of 2 723 kg of *A. thalassinus*, comprising 756 individuals, the largest measuring 1 000 mm TL. *Arius thalassinus* occurred only on the western coast of Mafia Island and the highest catch rate was 19.3 kg.fisher^{-1}.day^{-1} in March when murky water was predominant. The reproductive biology of *A. thalassinus* was investigated to assess its vulnerability to fishing. *Arius thalassinus* reached a size at first maturity (L_{M50}) of 520 mm TL and exhibited a low mean (±SE) fecundity of 65.6 ± 3.37 eggs per female within the size range of 605-970 mm TL. The hydrated oocytes were large (mean diameter ±SE = 15.2±0.12 mm). *Arius thalassinus* spawned once in the study year during February and April, during heavy precipitation (124-499 mm). We therefore conclude that its restricted distribution, large size, low fecundity, late maturation and its reported high trophic level indicate that it would be vulnerable to fishing pressure. It is therefore recommended that fishing for *A. thalassinus* be restricted during its spawning season to ensure its sustainability.

INTRODUCTION

Catfishes (Order Siluriformes) are mostly freshwater fishes but two families (the Ariidae and Plotosidae) inhabit murky marine or brackish waters (Moyle & Cech Jr, 2004). These two families of sea catfish are regarded as unusual in that they live primarily in tropical and subtropical seawater, unlike the majority of catfish families that have little tolerance for brackish or marine conditions (Moyle & Cech Jr, 2004). The giant sea catfish, *Arius thalassinus* (Rüppell, 1837), is among 23 species of sea catfish that are mostly confined

Corresponding author: ATK
Email: kamukuru@udsm.ac.tz

to murky coastal waters in the western Indian Ocean, within a depth range from 10 to 195 m (Fischer & Bianchi, 1984), and it is native to Tanzania (Bianchi, 1985).

Studies on the distribution and biology of sea catfishes in Tanzanian coastal waters are still sparse. Bianchi (1985) recorded five species of the genus *Arius* (Family Ariidae) and two species of the genus *Plotosus* (Family Plotosidae) along the Tanzanian coast. All were found in shallow coastal waters, predominantly brackish, around major river mouths. *Arius* spp. are of high economic value and are caught using mainly hook and line, shore seines, shark nets and fixed traps (Fischer & Bianchi, 1984; Bianchi, 1985). Catch statistics have revealed the high value of ariid catfishes as they constitute 7% of the total fish caught in the Rufiji Delta, compared to Mafia Island where their contribution is significantly lower at 0.6% (MLFD, 2007).

Ariid catfishes furthermore are carnivorous, feeding predominantly on crabs, prawns, mantis shrimps, fishes and molluscs (Taylor, 1986). They inhabit murky water, foraging by using one to four pairs of barbels (Moyle & Cech Jr., 2004), a characteristic of catfishes. Their ecological and reproductive characteristics include gonochorism, characterised by large-sized oocytes (Etchevers, 1978; Yáñez-Arancibia & Lara-Domínguez, 1988), and low fecundity (Bruton, 1995), with the males being oral incubators (Shadashiv & Vivekanandan, 2008). Studies have confirmed that parental care is exhibited by *A. thalassinus,* as the fertilised eggs are carried in the buccal cavity of males for a month (Mojumder, 1978; Menon, 1991). Furthermore, giant sea catfish males refrain from feeding while carrying eggs, embryos or fry (Menon, 1991).

O'Malley (2010) defined vulnerability as the intrinsic aspects in a species' biology, such as its life history or ecological variables, which increases its sensitivity to or inhibits its recovery from an external threat. Morphological characteristics, life history and ecological traits such as area occupancy and rarity (Hawkins *et al*., 2000) and large body size, slow growth, late maturity, low reproductive output and high trophic level (Jennings *et al*., 1999), have been used to predict the vulnerability of marine fishes to fishing. The sex ratio in a species and evidence of parental care, spawning aggregations or sex change have also been considered predictors of vulnerability of marine fishes to fishing (Reynolds *et al*., 2001).

Following the collapse of some fish stocks (Hutchings & Myers, 1996; Roberts & Hawkins, 1999; Hutchings & Reynolds 2004) and fishing threats to existing stocks (Sadovy & Cheung, 2003; Cheung, 2007), overfishing has remained the most pervasive threat to commercial marine fishes (Pitcher, 1998). Other threats to wild fish stocks include loss of essential habitats critical to complete their life cycle (Watling & Norse, 1998), climate change (Brander, 2010) and pollution (Sindermann, 1994). Currently, about 75% of wild fish stocks have been determined to be fully exploited (52%), overexploited (16%) or depleted (7%) (Botsford *et al*., 1997).

Published information on the distribution and biological characteristics of *A. thalassinus* at Mafia Island is meagre. This study aimed to provide preliminary observations on the occurrence and some biological aspects of *A. thalassinus* at Mafia Island, especially those likely to predispose it to high fishing mortality.

METHODS

Study area

The Mafia District comprises a chain of small islets, with the main island centred at 7°50′S and 39°45′E some 20 km off the Tanzanian coastline east of the Rufiji Delta (Fig. 1). Mafia Island is one of 169 administrative districts in Tanzania, with a population of 46 438 inhabitants living in 20 villages (URT, 2013). The island consists of Pleistocene reef covered by a sandy, loam soil. It experiences two monsoon seasons with an annual precipitation of 1 655 mm (Kamukuru, 2003), this figure being derived from rainfall data for Mafia Island obtained from a 1937-1973 dataset (Greenway *et al*., 1988) and the Agriculture Office, Mafia District Council for 1979-2010.

People depend largely on agriculture, notably coconut cultivation, and artisanal fishing on Mafia, the latter being restricted to inshore waters due to a lack of capital to purchase larger fishing vessels to engage in deep sea fishing (McClanahan *et al*., 2009). Two sites were studied, Kilindoni and Mfuruni, which lie within the most intensively fished area at Mafia Island (Kamukuru *et al*., 2005) at which one incident of dynamite fishing is reported per month (Horrill & Ngoile, 1992). The fishing grounds are dominated by sand, bare rock and rubble (Kamukuru *et al*., 2004) and occasional murky water (Roitenbeek *et al*., 2005), probably originating from the Rufiji Delta which has the largest single mangrove ecosystem in East Africa (UNEP, 2001).

Data collection

A survey was launched at all fish landing sites around Mafia Island in October 2010 to determine the occurrence of ariid catfish in the catches. It was evident that they were familiar to fishers on the western side of Mafia Island between the Kitoni and Tumbuju fish landing sites (Fig. 1). Giant sea catfish specimens were landed on roughly seven days each month at the Kilindoni and Mfuruni fish landing sites by fishers using longlines, seine nets and shark nets. These were sampled between November 2010 and October 2011. Information on the number of fishers per boat, gear used and locality caught was recorded. The total length (TL) of the giant sea catfish was measured to the nearest millimetre, the total and eviscerated weight (TW and EW) to the nearest gram using a suspended digital balance, and the paired gonads (GW) to the nearest 0.1 g using a top-loading digital balance. Macroscopic gonadal maturation staging was undertaken following the key by Kaunda-Arrara and Ntiba (1997). Ovaries at maturity stage IV were preserved in plastic bottles containing Gilson's fluid for fecundity estimates and mean ova diameter determination. These were kept at room temperature for three months and regularly, vigorously agitated to release the eggs from the ovarian tissues. Mature, hydrated intra-ovarian oocytes were counted for individual fecundity estimates. The diameters of 20 randomly selected, hydrated oocytes from ten mature females were measured to the nearest 0.01 mm using a digital calliper.

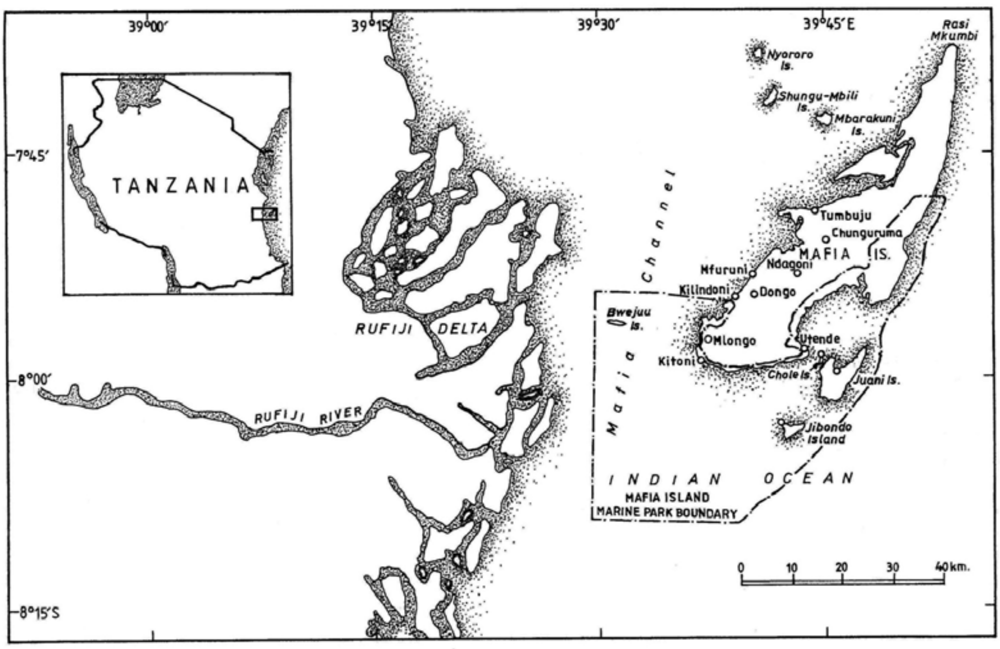


Figure 1. Map showing Mafia Island and position of the Rufiji Delta in Tanzania.

Data analysis

Relationships between TL and TW, and TL and fecundity (F), were estimated using least squares regression analysis and were derived from the equations:

$TW = a \times TL^b$ and $F = aTL \pm b$, respectively, where a is the intercept and b is the slope of the relationship (Le Cren, 1951). The monthly variation in gonadosomatic index (GSI), relative condition factor (*Kn*) and gonadal maturity stages were used to predict spawning periodicity in *Arius thalassinus*. The GSI was determined using the equation:

$$GSI = \frac{\text{Paired GW}}{\text{EW}} \times 100$$

. K*n* was determined using the equation:

$$Kn = \frac{TW}{aTL^b}$$

where, a and b are constants in the length-weight relationship (Le Cren, 1951). The length at which 50% of the fish were sexually mature was considered the size at first maturity (L_{M50}). This was estimated by fitting the percentage of mature individuals per 30 mm TL interval to an ogive function (Duponchelle & Panfili, 1998):

$$\%MF = \frac{1}{1 + e^{(-a(L - L_{M50}))}} \quad ;$$

where, %MF is the percentage of mature fish by size class, L is the mid-length of each size class, and a is a constant. Monthly variation in CPUE was analysed using single factor ANOVA and the post-hoc test followed the Tukey honestly significant difference (HSD) test. The sex ratio was analysed using the Chi-square test.

RESULTS

A total of 2 723.14 kg and 381.2 kg of *Arius thalassinus* and *Arius venosus*, comprising 758 and 152 individuals respectively, were measured at the Kilindoni and Mfuruni fish landing sites. Longlines contributed 85.9% to the total catch, with ring nets and shark nets contributing 7.2% and 6.9% respectively (Fig. 2a). The monthly variation in the giant sea catfish CPUE was not significant statistically (ANOVA: *df* = 11; F = 1.734; p = 0.078). The mean (±SE) CPUE peaked at 19.3±6.92 $kg.fisher^{-1}.day^{-1}$ in March with a minor peak at 10.1±1.22 $kg.fisher^{-1}.day^{-1}$ in December, coinciding with heavy (March/May) and light (November/December) rainy seasons, respectively (Fig. 2b).

Length-frequency distribution data revealed that the size of the giant sea catfish ranged between 390 and 1 000 mm TL, with an overall mean size (±SE) of 720.6±3.57 mm TL (Fig. 3a). Females (726.8±5.22 mm TL) grew to a similar size as males (714.1±4.91 mm TL) (t = 1.963; df = 756; p = 0.077). The length-weight relationship of *A. thalassinus* was significant (r = 0.92; F = 4227.8; df = 659; p <0.001), the equation being $TW = 2E-05 \times TL^{2.976}$ (Fig. 3b). The Student t-test for the length-weight relationship indicated that *A. thalassinus* exhibited isometric growth (t = -1.287; df = 657; p >0.05) with a length exponent of 2.976±0.045.

The overall sex ratio of *A. thalassinus* (F:M) was 0.99:1, conforming to unity (χ^2 = 0.05; df = 1; p >0.05). There was no significant evidence of size-dependent sex ratios but there were monthly differences in the sex ratio, with males being significantly fewer than females in April and May (Table 1). The species exhibited a single spawning season during February-April. This was inferred from peaking GSI and K*n* values in females in February, and in males in March. A sharp decrease in the GSI and K*n* for both sexes during May and June, presumably when the fish had released their gametes, indicated that they had concluded their reproductive cycle (Fig. 4). Evidence of this spawning season was further supported by the occurrence of a high proportion of fish with ripe and running gonads (stage IV) in February (Fig. 5). The sizes at first maturity of male and female *A. thalassinus* were 527.7 and 564.3 mm TL respectively (Fig. 6), with an overall L_{M50} of 520 mm TL.

Mature hydrated oocyte diameters ranged between 10 to 20 mm, the mean (±SE) being 15.2±0.12 mm, and their size

Table 1. Size and monthly variation in sex ratios of *Arius thalassinus* sampled at the Kilindoni and Mfuruni fish landing sites on Mafia Island between November 2010 and October 2011 (F = female; M = male; NS = not significant; df = 1; ** = p <0.01; *** = p <0.001).

TL (mm)	F	M	χ^2	Month	F	M	χ^2
350 - 400	1	0	1.00 NS	Jan	16	24	1.60 NS
400 - 450	1	1	0.00 NS	Feb	17	14	0.29 NS
450 - 500	1	3	1.00 NS	Mar	121	132	0.48 NS
500 - 550	15	16	0.03 NS	Apr	63	30	11.71***
550 - 600	25	34	1.37 NS	May	20	7	6.26**
600 - 650	30	40	1.43 NS	Jun	7	15	2.91 NS
650 - 700	65	71	0.26 NS	Jul	17	20	0.24 NS
700 - 750	110	109	0.00 NS	Aug	13	22	2.31 NS
750 - 800	65	55	0.83 NS	Sep	15	18	0.27 NS
800 - 850	21	15	1.00 NS	Oct	40	46	0.42 NS
850 - 900	20	28	1.33 NS	Nov	22	26	0.33 NS
900 - 950	13	6	2.58 NS	Dec	25	28	0.71 NS
950 - 1000	9	4	1.92 NS	TOTAL	376	382	0.05 NS
TOTAL	376	382	0.01 NS				

frequency distribution was unimodal at 16.5 mm (Fig. 7a). The number of hydrated oocytes per female ranged between 25 to 101, the mean count (±SE) being 65.6±3.37 ova per female in fish between 605-970 mm TL. The length-fecundity relationship was linear (F= 0.1216TL – 30.653) with a significant, positive correlation coefficient (r = 0.61; F = 17.39; df = 29, p <0.001) (Fig. 7b).

DISCUSSION

Two species of sea catfishes, viz. *Arius thalassinus* and *A. venosus*, were found on the western side of Mafia Island, with the former constituting 86% by weight of the catch. The preponderance of *A. thalassinus* at Mafia Island was probably due to its reported wider depth range (10-195 m), while *A. venosus* is restricted in coastal waters to a depth of 10 m (Fischer and Bianchi, 1984). Giant sea catfish were caught throughout the year, mostly during the rainy season, conforming to its preferred habitat of murky marine or brackish water which prevails in the Mafia Channel (Roitenbeek *et al*., 2005). This habitat has been described as ideal for carnivorous catfishes which forage using their barbels (Moyle & Cech Jr, 2004). Other parts of Mafia Island were devoid of ariid catfishes, partly due to the predominance of clear oceanic water that favours the development of coral reefs (Darwall & Guard, 2000) and other factors such as deeper waters devoid of soft bottoms.

A. thalassinus is a large-bodied fish which makes it a favoured catch and therefore vulnerable to fishing. It has been hypothesized that body size is negatively correlated to the intrinsic rate of natural increase in a species, and large-bodied fish thus generally have little ability to recuperate from high mortality events (Jennings & Reynolds, 2007). Furthermore, fishing activities target larger-bodied species more often, and receive disproportionately more fishing effort, than species of smaller body size (Reynolds *et al*., 2002).

Our results indicated that *A. thalassinus* spawned once per year during February-April in the northeast monsoon following the onset of the heavy rainy season. Similar findings were reported for the species in the Arabian Sea (Dmitrenko, 1970; Naama & Yousif, 1987) and India (Mojumder, 1978), with spawning lasting for two months during the

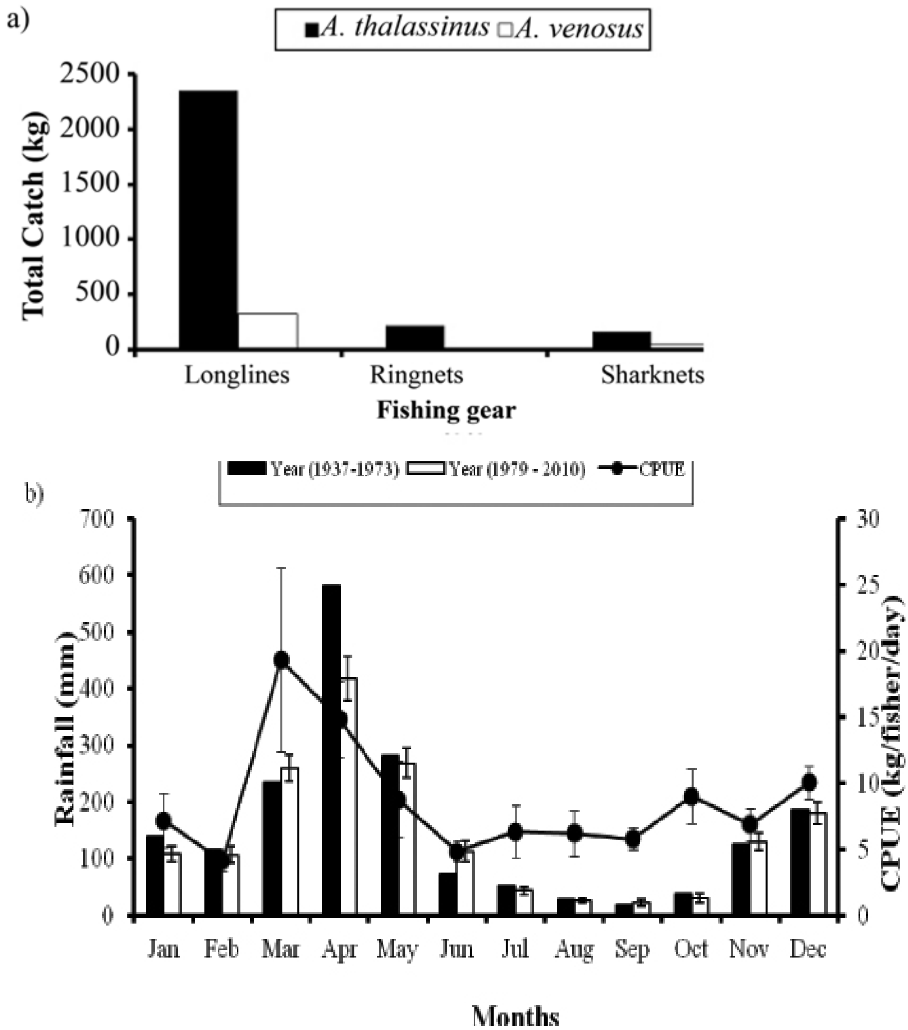
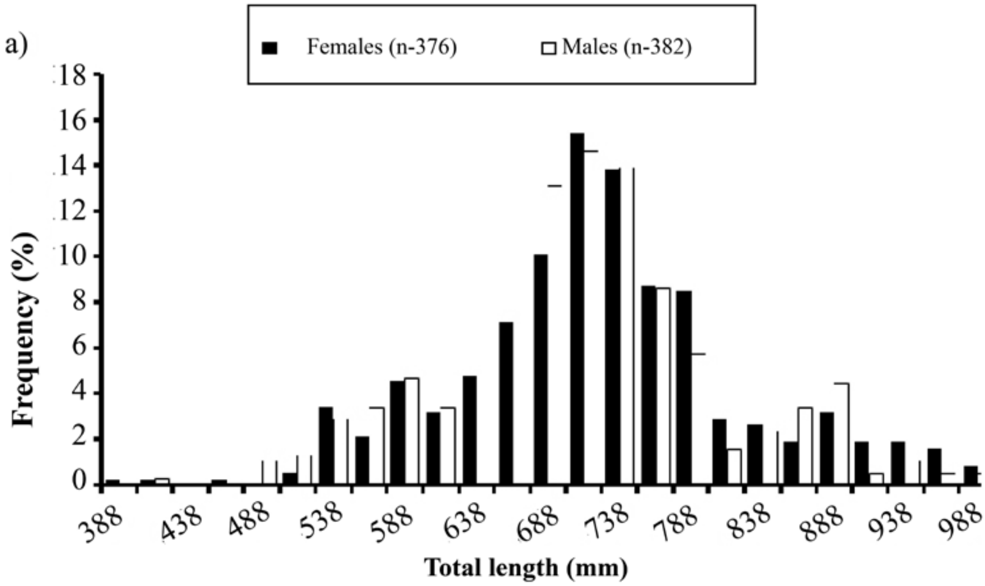


Figure 2. a) Total catch of ariid catfishes by fishing gear and b) monthly variations in rainfall during 1937-1973 (solid bars) and 1979-2010 (open bars) with mean CPUE (solid circle) of *Arius thalassinus* (error bar ±SE).

northeast monsoon. *Arius thalassinus* becomes sexually mature at a large size, and is a late maturer that produces relatively few eggs. Fecundity alone has been widely criticized as a measure of vulnerability (Sadovy, 2001; Sadovy & Cheung, 2003; Dulvy *et al*., 2005) but workers on elasmobranchs consider fecundity to be an important predictor of vulnerability (Brander, 1981; Stevens, 1999). After spawning, male sea catfishes assume the role of oral incubation (Dmitrenko, 1970; Mendoza-Carranza & Hernández-Franyutti, 2005; Shadashiv & Vivekanandan, 2008) and are believed to move from the fishing grounds (Mendoza-Carranza, 2003). This hypothesis is supported by our study in which a significant reduction in the number of males occurred in April-May, accompanied by the low GSI and *Kn* values associated with the post-spawning period.

Ariid catfishes have large oocytes compared to other teleosts, and mouth-brooders tend to have larger ova and therefore lower fecundity (Etchevers, 1978; Yáñez-Arancibia & Lara-Domínguez, 1988). *A. thalassinus* has large ova, the mature eggs



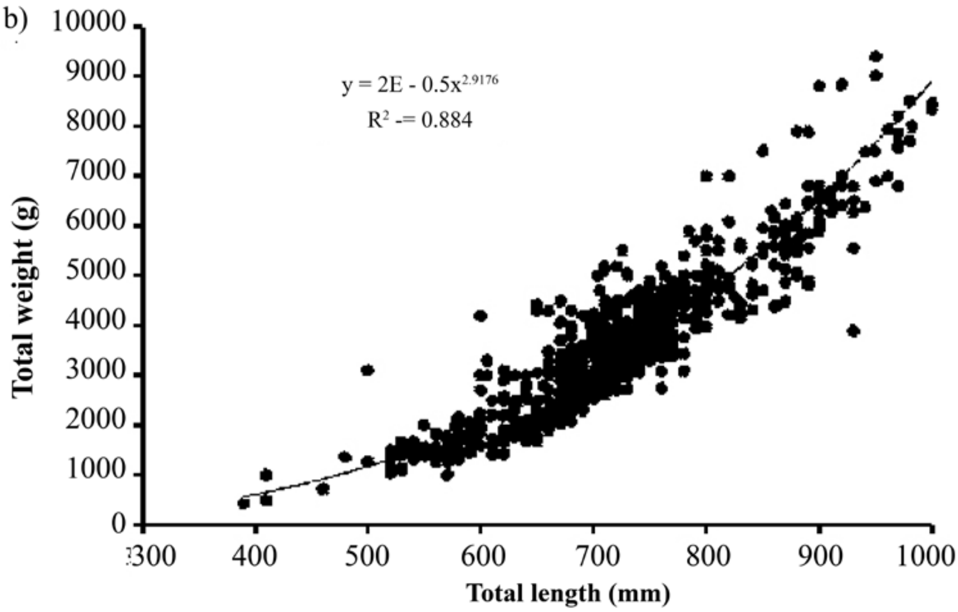


Figure 3. a) Length-frequency distribution of females (solid bar) and males (open bar) and b) length-weight relationship of *Arius thalassinus* (n = 758).

having a modal diameter of 16 mm which is typical of this group (Mojumder, 1978). The shortcomings of large ova and lower fecundity are, however, likely to be compensated by a low rate of egg and larval predation due to parental care rendered by male oral incubation (Menon, 1991). This strategy might well give this species an advantage in colonising suitable habitats and increasing its survival. However, drawbacks in the strategy include the fact that the size of the buccal capacity limits the number of eggs that can be incubated and are forced to lose a portion of the eggs when dealing with threats such as fishing gear

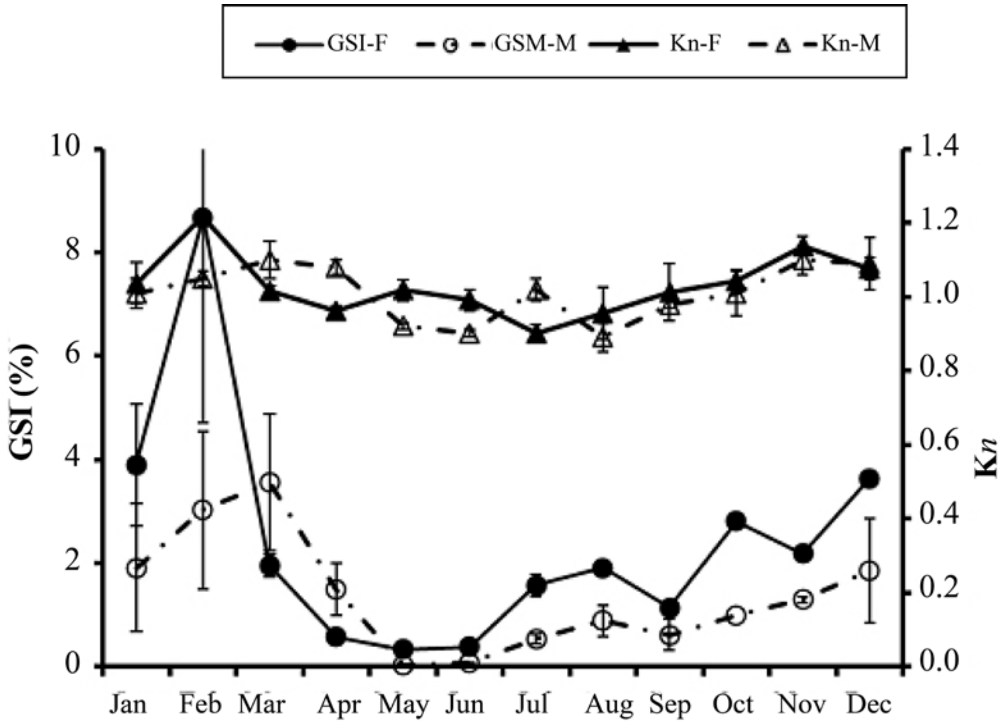


Figure 4. Monthly changes in GSI and Kn of female (solid line) and male (dashed line) *Arius thalassinus*.

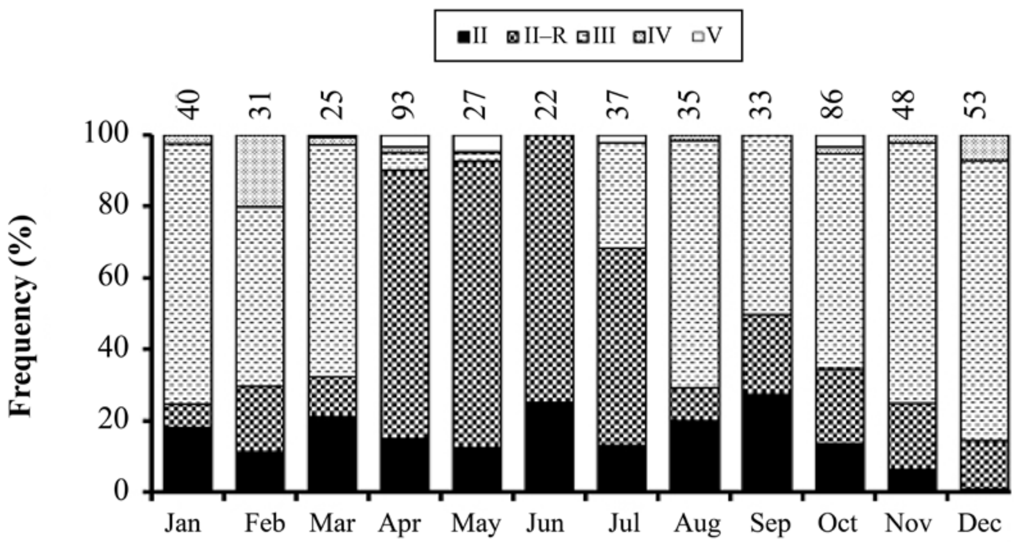


Figure 5. Monthly variations in gonadal maturity stages of *Arius thalassinus*: II = maturing; II-R = resting and recovering; III = active; IV = ripe and running; V = spent (sample N is indicated above the bars).

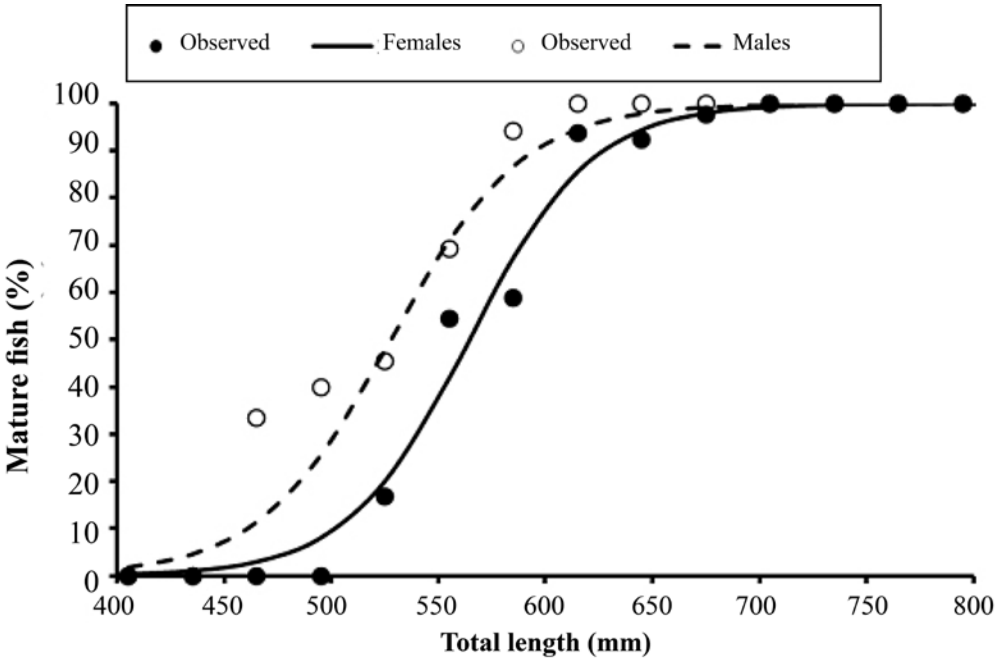


Figure 6. Size at first maturity of female (L_{M50} = 564.3 mm TL) and male (L_{M50} = 527.7 mm TL) *Arius thalassinus*.

(Shadashiv & Vivekanandan, 2008). Studies have also indicated that males feed on embryos to avoid starvation, and 'gestating males' have decreased condition, making them vulnerable to fishing and predation (Menon, 1991; Mendoza-Carranza & Hernández-Franyutti, 2005). This could not be confirmed in the present study as gestating males refrain from feeding (Mendoza-Carranza & Hernández-Franyutti, 2005; Shadashiv & Vivekanandan, 2008) and hence were not caught on baited longlines.

The current exploitation of *A. thalassinus* stocks seemed sustainable at Mafia Island, considering that the mean landed size was larger than the size at first maturity. However, the restricted distribution of this giant sea catfish, its rarity, low fecundity, late maturation and large size make it potentially vulnerable to overfishing. Moreover, little or nothing is known about the current status of *A. thalassinus* stocks at Mafia Island and a precautionary approach to its fisheries management is advisable.

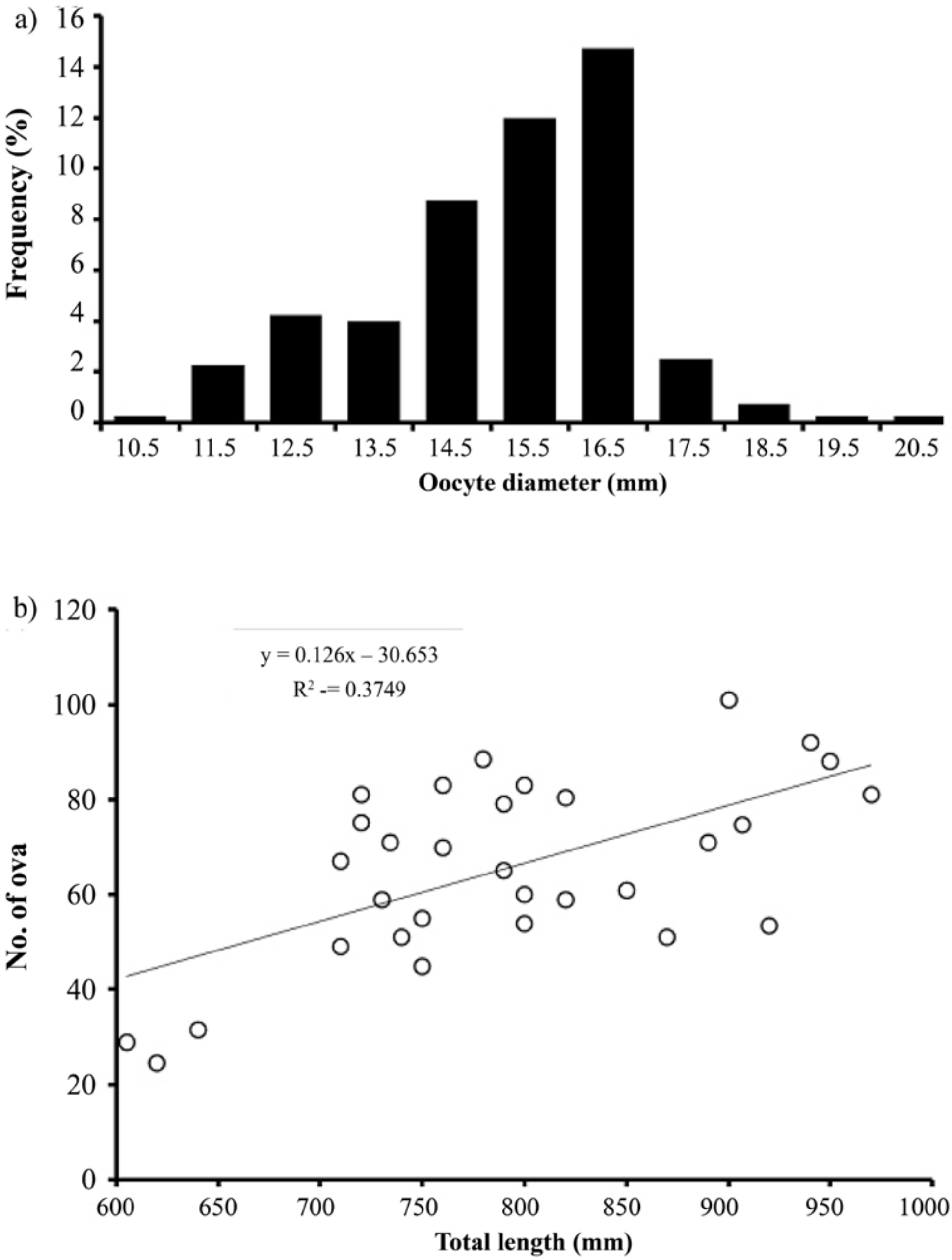


Figure 7. a) Mature hydrated oocyte size frequency distribution (n = 200) and b) length-fecundity relationship of *Arius thalassinus* (N = 31).

Acknowledgements – We would like to express our sincere gratitude to the staff of the Department of Livestock and Fisheries Development of the Mafia District Council for their dedicated assistance with fieldwork throughout the study. The study was fully financed by the Norwegian Cooperation Programme for Development, Research and Education – Project No. NUFUTZ-2007/1027, and involved collaboration between the

University of Dar es Salaam and the Norwegian University of Life Sciences. We are also grateful to the Kilindoni and Mfuruni fishers who participated in this study.

References

Bianchi G (1985) FAO Species Identification Sheets for Fishery Purposes: Field guide to the commercial marine and brackish water species of Tanzania. Prepared and published with the support of TCP/URT/4406 and FAO (FIRM) Regular Programme, Rome FAO, 199 pp

Botsford LW, Castilla JC, Peterson CH (1997) The management of fisheries and marine ecosystems. Science 277: 509-515

Brander K (1981) Disappearance of common skate *Raja batis* from the Irish Sea. Nature 290: 48-49

Brander K (2010) Impacts of climate change on fisheries. Journal of Marine Systems 79: 389-402

Bruton MN (1995) Have fishes had their chips? The dilemma of threatened fishes. Environmental Biology of Fishes 43: 1-27

Cheung WL (2007) Vulnerability of marine fishes to fishing: From global overview to the northern South China Sea. PhD thesis, University of British Columbia, 354 pp

Darwall WRT, Guard M (2000) Southern Tanzania. In: McClanahan TR, Sheppard CRC, Obura D (eds) Coral reefs of the western Indian Ocean: Their ecology and conservation. Oxford University Press, New York, pp 131-165

Dmitrenko YM (1970) Reproduction of the sea catfish, *Arius thalassinus* (Rupp.) in the Arabian Sea. Journal of Ichthyology 10: 634-641

Dulvy NK, Jennings S, Goodwin NB, Grant A, Reynolds JD (2005) Comparison of threat and exploitation status in North-East Atlantic marine populations. Journal of Applied Ecology 42: 883-891

Duponchelle F, Panfili J (1998) Variations in age and size at maturity of female Nile tilapia, *Oreochromis niloticus*, populations from man-made lakes of Côte d'Ivoire. Environmental Biology of Fishes 52: 453-465

Etchevers SL (1978) Contribution to the biology of the sea catfish *Arius spixii* (Agassiz) (Pisces-Ariidae), South of Margarita Island, Venezuela. Bulletin of Marine Science 28: 381-385

Fischer W, Bianchi G (1984) FAO species identification sheets for fishery purposes. Western Indian Ocean (Fishing Area 51). Danish International Development Agency (DANIDA)/ Food and Agricultural Organisation of the United Nations. Rome FAO. Vols. 1-6: pp var

Greenway PJ, Rodgers WA, Wingfield RJ, Mwasumbi LB (1988) The vegetation of Mafia Island, Tanzania. Kirkia 13: 197-212

Horrill JC, Ngoile MAK (1992) Results of the physical, biological and marine resource use surveys: Rationale for the development of a management strategy. Mafia Island Project Report No. 2. The Society of Environmental Exploration, London/University of Dar es Salaam, Dar es Salaam, 46 pp

Hawkins JP, Robert, CM, Clark V (2000) The threatened status of restricted-range coral reef fish species. Animal Conservation 3: 81-88

Hutchings JA, Myers RA (1996) What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Canadian Journal of Fisheries and Aquatic Sciences 51: 2126–2146

Hutchings JA, Reynolds JD (2004) Marine fish population collapses: Consequences for recovery and extinction risk. BioScience 54: 297-309

Jennings S, Reynolds JD, Polunin NVC (1999) Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. Conservation Biology 13: 1466-1475

Jennings S, Reynolds JD (2007) Body size, exploitation and conservation of marine organisms. In: Hildrew AG, Raffaelli DG, Edmonds-Brown R (eds) Body size: the structure and function of aquatic ecosystems. Cambridge University Press, Cambridge, pp 266-285

Kamukuru AT (2003) Effects of fishing on growth and reproduction of blackspot snapper, *Lutjanus fulviflamma* (Pisces: Lutjanidae) in shallow waters of Mafia Island, Tanzania PhD Thesis, University of Dar es Salaam, Tanzania 273 pp

Kamukuru AT, Hecht T, Mgaya YD (2005) Effects of exploitation on age, growth and mortality of the blackspot snapper, *Lutjanus fulviflamma* (Lutjanidae) at Mafia Island, Tanzania. Fisheries Management and Ecology 12: 45-55

Kamukuru AT, Mgaya YD, Öhman MC (2004) Evaluating a marine protected area in a developing country: Mafia Island Marine Park, Tanzania. Ocean and Coastal Management 47: 321-337

Kaunda-Arara B, Ntiba MJ (1997) The reproductive biology of *Lutjanus fulviflamma* (Forsskål 1775) (Pisces: Lutjanidae) in Kenyan inshore marine waters. Hydrobiologia 353: 153-160

Le Cren AD (1951) The length-weight relationship and seasonal cycle in gonad weight and condition in the perch *Perca fluviatilis*. Journal of Animal Ecology 20: 201-219

McClanahan TR, Cinner J, Kamukuru AT, Abunge C, Ndagala J (2009) Management preferences, perceived benefits and conflicts among resource users and managers in the Mafia Island Marine Park, Tanzania. Environmental Conservation 35: 340-350

Mendoza-Carranza M (2003) The feeding habits of gafftopsail catfish Bagre marinus (Ariidae) in Paraíso Coast, Tabasco, México. Hidrobiológica 13: 113-126

Mendoza-Carranza M, Hernández-Franyutti A (2005) Annual reproductive cycle of gafftopsail catfish, *Bagre marinus* (Ariidae) in a tropical coastal environment in the Gulf of Mexico. Hidrobiológica 15: 275-282

Menon NG (1991) Oral incubation in marine catfishes of the family Tachysuridae. Indian Journal of Fisheries 38: 30-34

MLFD (2007) Ministry of Livestock and Fisheries Development. Annual Fisheries Report, Fisheries Division, Tanzania

Mojumder P, (1978) Maturity and spawning of the catfish, *Tachysurus thalassinus* (Rüppell) off Waltair coast. Indian Journal of Fisheries 25: 109-121

Moyle PB, Cech-Jr JJ (2004) Fishes an Introduction to Ichthyology 5th ed. Prentice-Hall, Inc. Upper Saddle River, 726 pp

Naama AK Yousif UH (1987) Some observations on spawning and fecundity of Arius thalassinus (Rupp.) in Kohr al-Zubair, Iraq. Indian Journal of Fisheries 34: 476-478

O'Malley SL (2010) Predicting vulnerability of fishes. MSc thesis. Department of Ecology and Evolutionary Biology, University of Toronto, Canada, 53 pp

Pitcher TJ (1998) A cover story: Fisheries may drive stocks to extinction. Reviews in Fish Biology and Fisheries 8: 367-370

Reynolds JD, Jennings S, Dulvy NK (2001) Life histories of fishes and population responses to exploitation. In: Reynolds JD, Mace GM, Redford KH, Robinson JG (eds) Conservation of exploited species. Cambridge University Press, Cambridge, pp 148-168

Reynolds JD, Dulvy NK, Roberts CM (2002) Exploitation and other threats to fish conservation. In: Hart PJB, Reynolds JR (eds) Handbook of Fish Biology and Fisheries. Wiley-Blackwell, Malden, MA pp 319-341

Roberts CM, Hawkins JP (1999) Extinction risk in the sea. Trends in Ecology and Evolution 14: 241–246

Roitenbeek J, Hewawasam I, Ngoile M (eds) (2005) Blueprint 2050: Sustaining the marine environment in mainland Tanzania and Zanzibar. World Bank 125 pp

Sadovy Y (2001) The threat of fishing to highly fecund fishes. Journal of Fish Biology 59: 90-108

Sadovy Y, Cheung WL (2003) Near extinction of a highly fecund fish: The one that nearly got away. Fish and Fisheries 4: 86-99

Shadashiv GR, Vivekanandan E (2008) Vulnerability of catfish to fishing: an investigation based on the landings at Mumbai. Indian Journal of Fisheries 55: 227-233

Sindermann CJ (1994) Quantitative effects of pollution on marine and anadromous fish populations. NOAA Technical Memorandum, NMFS-F/NEC-104, US Department of Commerce, National Technical Information Services, Springfield, Virginia 22 pp

Stevens JD (1999) Variable resilience to fishing pressure in two sharks: the significance of different ecological and life history parameters. In: Musick JA (ed) Life in the slow lane: Ecology and conservation of long-lived marine animals. American Fisheries Society Symposium Vol. 23, Bethesda, pp 11-15

Taylor WR (1986) Ariidae. In: Daget J, Gosse JP, Thys van den Audenaerde DFE (eds) Check-list of the freshwater fishes of Africa (CLOFFA). ISBN, Brussels; MRAC, Tervuren; and ORSTOM, Vol. 2, Paris, pp 153-159

UNEP (2001) United Nations Environment Programme, Eastern Africa atlas of coastal resources, Tanzania. A project of the UNEP with support of the Government of Belgium, Nairobi, 111 pp

URT (2013) United Republic of Tanzanian, 2012 population and housing census, population distribution by administrative areas. National Bureau of Statistics, Dar es Salaam, 244 pp

Watling L, Norse EA (1998) Disturbance of the seabed by mobile fishing gear: A comparison to forest clear-cutting. Conservation Biology 12: 1180-1197

Yáñez-Arancibia A, Lara-Domínguez AL (1988) Ecology of three sea catfishes (Ariidae) in a tropical coastal ecosystem – Southern Gulf of Mexico. Marine Ecology Progress Series 49: 215-230