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The fishery of *Balistes capriscus* (Balistidae) in Ghana and possible reasons for its collapse

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Abstract

The fish catch statistics of grey triggerfish (*Balistes capriscus*) in Ghana from 1972 to 2003 have suggested a possible 'regime shift' of triggerfish in coastal waters of Ghana. This suggests possible influence of local environmental parameters (sea surface temperature, salinity and coastal wind speed) and/or exploitation on grey triggerfish resource. The observed variability in environmental conditions and triggerfish landings off Ghana occurred seasonally. Time series analyses of sea surface temperature, salinity and coastal wind speed from alongshore recording stations of Marine Fisheries Research Division in Tema, Ghana and Ghana Meteorological Agency over the period 1974-2004 suggest possible link between local environmental parameters and triggerfish catch in Ghana. Again, the identification of maximum mean temperature partitioning (between the periods 1972-76 and 1985-89) and maximum mean critical temperature (in 1987) support the notion of the contribution of sea warming in the disappearance of the triggerfish resource. Pre-1979 regime coincided with the intensification of major upwelling in 1975-1978 with its corresponding strong wind fields in 1975-1978 along the east coast of Ghana. The 1979 catch interface experienced unusual high temperature conditions during major cooling period which might have played an important role in the high abundance of triggerfish. Between 1979 and 1987, triggerfish landings and cooling events were normalised. The 1987 catch interface experienced unusual high sea temperature during major cooling period which might have played an important role in the high abundance of triggerfish. The 1987 regime coincided with weak wind fields during cooling periods (less intense) which was the expected condition that might have triggered migration of grey triggerfish. Regime III (1987 – 2004) experienced a sharp decline (collapse phase) of triggerfish landings. The similarities in the sea conditions at the collapse phase (regime III) and before or during invasion phase (regime I) of triggerfish resource in coastal waters of Ghana suggest a possible influence of extreme temperatures on triggerfish fluctuations. The insights from the seasonal time series analysis of salinity and wind speed suggest their seasonal control of sea temperature and hence the major coastal cooling along the coast of Ghana.

Size-weight relationships of grey and blue-spotted triggerfish indicate that for a given size grey triggerfish tends to weigh less than blue-spotted triggerfish. However, in both equations the exponent for length is sufficiently close to 3.0, a situation which indicates that *B. capriscus* and *B. punctatus* grow isometrically. The maximum size of grey triggerfish observed in this study was higher than that previously reported. The increased maximum size of grey triggerfish in this study suggests that the fish species had not been a target fish for the artisanal fishery since its collapse in late 1980s, and therefore the fish is able to live for quite a longer period of time before it risks the chance of being caught. The maximum age of triggerfish in this study was age 11 which is lower than previously reported age of grey triggerfish in northeastern Gulf of Mexico. The back-calculated lengths for grey triggerfish in this study are much comparable to results on the same fish species from northeastern Gulf of Mexico; and much closer to queen triggerfish from U.S. Virgin Islands and Puerto Rico. The asymptotic length, L_∞ was greater and rate of growth, K slower than previously reported for the grey triggerfish in Ghana. Nevertheless, the rate of growth was comparable to that previously reported for grey triggerfish in Côte d'Ivoire. The mean of L_∞ for *Balistes capriscus* for both sexes in Senegal, Côte d'Ivoire and Ghana is 40.83±0.09 (SE) for 95 % confidence interval; whereas the L_∞ for *B. capriscus* in this study is 45.1±1.4 (SE) estimated

from the observed data. The estimated natural mortality, *M* for grey triggerfish (0.40) in this study (derived from Rikhter and Efanov's method) was found to be lower than Ofori-Danson's estimates (0.81) on Ghana grey triggerfish stocks in 1980. However, *M* estimate (0.39) of grey triggerfish in Senegal waters was quite comparable to value obtained in this study. Again, it was observed that *M* in many cases was higher than or closer to total mortality (*Z*). This could be true because the mortality of triggerfish in recent times is mainly due to natural causes rather than fishing activities since the resource had disappeared for nearly two decades in coastal waters of Ghana. Despite the slight changes in L_∞ and *K* in both the western and eastern stocks of grey triggerfish, the growth performance of the species has remained virtually the same in both periods of its dominance and collapse in the West African waters. The derived growth performance of grey triggerfish in this study is comparable to that previously reported in Senegal waters. There are no previous reports on growth performance of blue-spotted triggerfish but this study obtained values comparable to that of grey triggerfish in Côte d'Ivoire in 1982. Grey triggerfish exploitation ratio (0.2727) obtained in this study shows that the triggerfish resource is underexploited as compared to the exploitation ratio of 0.67 derived from 1980 growth results of grey triggerfish. Thus, triggerfish resource might not have been over-exploited before their disappearance. There is indication that *Balistes capriscus* and *Balistes punctatus* have habitat overlap in the western Gulf of Guinea. The gut analysis of *B. capriscus* and *B. punctatus* indicate that both triggerfish species are more planktivorous at juvenile stage (12.0-21.9 cm size class) and more benthivorous at later stage in life. It suggests there could be competition for food resources (benthic macroinvertebrates) between the two fish species at the later stage of their development. However, it appears *B. capriscus* is better adapted in terms of benthic life as the species occur at deeper depth of coastal waters and therefore, better selected for benthic feeding. For this reason, *B. capriscus* might have a competitive advantage over *B. punctatus* at benthivorous stage. In that sense, *B. punctatus* growth at later stage might be affected negatively and hence stunting could result in *B. punctatus*. The gut analysis of *B. capriscus* in this study is much comparable to the previous stomach content analysis in 1980 and hence, the possibility of change in diet might not have been the cause of triggerfish disappearance in Ghanaian coastal waters.

1 Introduction

The coast of Ghana is one of the most important areas concerning fish abundance in West Africa (Koranteng 2002; Mensah and Quaatey 2002). It has a coastal length of 539 km, a continental shelf area of 23,700 km^2 and an exclusive economic zone (EEZ) of 235 349 km^2 (Food and Agriculture Organisation, FAO 1998; Horemans 1996; FISHBASE 2006). Ghanaian coastal waters form part of the western Gulf of Guinea statistical division of FAO Committee for Eastern Central Atlantic Fisheries (CECAF). The three other countries in this statistical division are Côte d'Ivoire, Togo and Benin. These countries share a number of fish stocks (Koranteng 1996, 1998; Mensah and Quaatey 2002) with the total marine fish catch off Ghana and Côte d'Ivoire at 481 985 tonnes in 1999, 429 775 tonnes in 2001 and 361 659 tonnes as at 2003 (FAO 2005). Out of these totals, Ghana's catch contribution represents 86.8 %, 85.4 % and 87.3 % in 1999, 2001 and 2003 respectively. The abundance of fish is partly due to the upwelling events in the Gulf of Guinea. The upwelling creates a congenial environment as a result of nutrient-rich water masses welled up into euphotic zone for increased primary production and subsequently food for higher trophic levels and hence high fish production; and also, the prevailing current at the West African coastline, the Guinea Current, influences the nearshore conditions off Ghana (Binet and Marchal 1993). The wind system act on the water masses and creates two upwelling periods during the year, usually between July and September (major upwelling) and between January and March (minor upwelling)-(Pezennec 1984; MFRD 1988). Artisanal fisheries along Ghana's coast is operating from 304 landing beaches in 185 fishing villages as at 2001 (Bannerman *et al.* 2001) using mostly wooden dugout canoes for nearshore fishing and to a lesser extent seine net fisheries directly at the beaches. The total number of fishermen operating along the coast of Ghana as at 2001 is 123 156 (Appendix, Table 13).

1.1 Fishery resources exploited in Ghana (western Gulf of Guinea)

The fishery resource in the Gulf of Guinea is classified into small pelagics, large pelagics, demersals, crustaceans and molluscs (Mensah and Quaatey 2002). The resource is exploited by artisanal, semi-industrial and industrial fishery sectors in Ghana. Important pelagic fishery resource exploited in the EEZ of Ghana include: Clupeidae (eg. *Sardinella aurita, S. maderensis, Ilisha africana*), Engraulidae (*Engraulis encrasicolus*), Carangidae (*Decapterus rhoncus, D. punctatus, Trachurus trecae, Selene dorsalis, Chlorosombrus chrysurus, Alectis alexandrinus*) and Scombridae (*Scomber japonicus*) (Mensah and Quaatey 2002; MFRD 2002; Mehl *et al*. 2004, 2005). Most important coastal demersal fishery resources exploited in Ghana include: Sparidae (*Pagellus bellottii, Sparus caeruleostictus, Dentex canariensis, D. gibbosus, D. congoensis*), Haemulidae/Pomadasyidae (*Pomadasys incisus, P. jubelini, Brachydeuterus auritus*), Sciaenidae (*Pseudotolithus senegalensis, P. typus, Umbrilla canariensis*), Lutjanidae (*Lutjanus fulgens, L. agennes, L. goreensis*), Balistidae (*Balistes capriscus, B. punctatus*), Mullidae (*Pseudupeneus prayensis*), Serranidae (*Epinephelus aeneus*) and Polynemidae (*Galeoides decatactylus*) (Koranteng 1998, 2002; MFRD 2002; Mehl *et al*. 2004, 2005) (Table 1). The strong patterns of fish variability in the last few decades in Ghana and Cote d'Ivoire as seen in pelagics such as *Sardinella aurita* and demersal fish appear to be connected in some way, through interactions between species or communities or through environmental forcing (Cury and Roy 2002).

Table 1: Important fishery resources exploited in exclusive economic zone of Ghana (capture data from FAO fishery statistics 1983, 1987, 1998 and 2006)

Resource	Families	Species	Common English Name	Capture (tons)				
				1979	1987	1992	2002	2004
Small pelagic	Clupeidae	*Sardinella aurita*	Round sardinella	-	47407	125814	64300	82396
		Sardinella maderensis	Flat sardinella	-	27177	14410	13755	27052
	Scombridae	*Scomber japonicus*	Chub mackerel	97	746	11982	7018	6010
	Engraulidae	*Engraulis encrasicolus*	Anchovy	36676	87984	85384	57639	52629
	Carangidae	*Decapterus spp*	Scads	-	-	993	2944	1435
		Trachurus spp	Jack & horse mackerel	844	36	762	504	2714
		Selene dorsalis	African moonfish	1950	4555	1202	690	1479
		Chlorosombrus chrysurus	Atlantic bumper	3854	5422	5153	5670	5747
		Caranx hippos	Crevalle jack	1851	3278	5321	2872	9111
		Caranx rhonchus	False scad	8612	3234	2472	1605	2016
	Sphyraenidae	*Sphyraena spp*	Barracudas	1008	3773	1753	1193	3541
Large pelagic	Scombridae	*Thunnus albacares*	Yellowfin tuna	528	10830	7300	23499	15137
		Thunnus obesus	Bigeye tuna	171	1000	-	5893	6944
		Katsuwonus pelamis	Skipjack tuna	4200	24347	23756	31887	33600
		Euthynnus alletteratus	Little tunny	5547	5551	11608	4768	7060
		Istiophorus albicans	Atlantic sailfish	2691	2325	297	529	503
Coastal demersal	Sparidae	*Pagellus bellottii*	Red pandora	-	7789	8724	3132	4922
	Haemulidae	*Brachydeuterus auritus*	Bigeye grunt	15010	16627	11024	9267	26456
	Balistidae	*Balistes spp*	Triggerfish	13326	18283	198	12	1
	Sciaenidae	*Pseudotolithus spp*	West African croakers	2453	2379	2340	1067	1126
	Lutjanidae	*Lutjanus spp*	Snappers	361	948	635	774	756
		Pagrus spp	Pargo breams	754	718	1200	2624	461
	Mullidae	*Pseudupeneus prayensis*	West African goatfish	988	737	247	278	427
	Serranidae	*Epinephelus spp*	Groupers	1186	800	225	233	231
	Polynemidae	*Galeoides decatactylus*	Lesser African threadfins	-	3313	1826	2204	3098
Deep water demersal	Sparidae	*Dentex angolensis*	Angolan dentex	190	-	284	990	1975
	Trichiuridae	*Trichiurus lepturus*	Largehead hairtail	2646	2157	4341	3154	1760

1.1.1 *Hypothesis I*

The sudden collapse of *Balistes capriscus* is mainly due to significant changes in oceanographic conditions over the period 1974-2004 greatly affecting the habitat of the stock.

In this hypothesis, a reconstruction of extreme hydrographic events in coastal waters of Ghana over three decade period was assessed. These extreme events were related to the catches of *Balistes capriscus* in Ghana. It was reported that *B. capriscus* almost disappeared from the West African ecosystems at the end of the 1980s and recent reports (Mehl *et al*. 2004, 2005) show that there are just traces of the species present in the region (IMR 1989), indicating its fishery collapse in the area. It was documented that the region recorded below estimated potential yield of the species in the 1980s (Mensah and Quaatey 2002). Hence, their conclusion was that the triggerfish stock was not over-exploited. Koranteng and McGlade (2001) identified climatic periods that had remarkable synchrony with the events that have occurred in the fisheries in continental shelf waters of the western Gulf of Guinea. At present, only few published information exist that look at the seasonal and interannual fluctuations of local environmental forcing and the possible link to fishery fluctuations in the western Gulf of Guinea.

1.1.2 *Hypothesis II*

The collapse of *Balistes capriscus* can be mainly attributed to the effect of the fishing eg. recruitment, growth, overfishing and possible diet change of the stock.

This hypothesis was to compare the periods of dominance and collapse of *Balistes capriscus* in terms of growth, food condition (stomach contents and prey availability) and growth performance. Possible diet shift of triggerfish in the western Gulf of Guinea was ascertained as a result of the fishery collapse. Triggerfish is carnivorous as well as omnivorous (Ofori-Adu 1987, 1994). The species is basically a demersal fish which feeds mainly on benthic invertebrates like marine molluscs and crustaceans (Ofori-Danson 1981).

1.2 Climatic change and fisheries in Gulf of Guinea

Understanding fluctuations in marine fish stocks is important for fisheries management, as such increasing attempts have been made to demonstrate links with oceanographic and climatic variability. The effect of environmental variability on marine population dynamics remains a challenging problem for fisheries science (Cury *et al.* 1995, Cury *et al.* 2000). Impressive interdecadal "regime shifts" in marine fish populations have recently occurred simultaneously in widely-separated large marine ecosystems (LMEs) of the Pacific. There has been regime shifts in the global climate in 1976/1977 (confirmed, with a marked effect on the dynamics of North Pacific ecosystems from low trophic plankton production to fisheries resources); that of 1988/89 and the late 1990s are not properly understood. According to Pörtner and Knust (2007), climate change is envisaged to have effect on individual organisms, the size and structure of their populations, the species composition of communities, and the structure and functioning of ecosystems. The need to understand the nature of such regime shifts, as well as their connotations to fishery management, is becoming recognized as one of the most crucial new problem areas in fisheries science (Bakun 1993). There has not been any comprehensive understanding of these regime shifts, however, Pörtner and Knust (2007) acknowledged the possibility of physiological studies to address the mechanisms and reasons for the thermal sensitivity of organisms. They further revealed that the mortality or reduction in abundance of organisms is not only caused by unsuitable temperature but also the period of exposure is very crucial. The mechanism and reason for the mortality in organisms is the reduction in aerobic performance which results in decreased growth usually first seen among larger specimens. The reduction in abundance becomes evident when all size groups of a population are affected (Pörtner and Knust 2007).

Bakun (1993) observed two separate classes of global-scale climatic effects which could have conceivably control the dramatic coastal pelagic population changes that had occurred in the Gulf of Guinea over the past two decades. One is a long-term intensification of coastal upwelling that may be related to global climate change. The other involves global climatic teleconnections to the Pacific El Nino Southern Oscillation (ENSO) system. The two global climatic effects appear to suggest opposite scenarios concerning the future of the local fishery. Presently, there is no sound scientific basis available for choosing between them, illustrating a need for basic research to support policy and management decisions on fisheries.

There are three general categories of oceanographic process considered to be important in influencing fish recruitment success; namely *enrichment*, *concentration* and *retention* (Hardman-Mountford and McGlade 2002, Bakun 2006). Bakun refers to these three factors as a fundamental triad. The nutrient enrichment processes are: upwelling, river run-off and micro-scale turbulence which support primary production. Concentration of food particles into denser aggregations that facilitates foraging occurs in areas such as fronts, river plumes and the thermocline. Features that constitute retention and transport of eggs and larvae to suitable nursery areas are fronts, coastal boundaries, thermocline, currents and local gyral circulation patterns (Mendo *et al.* 1987, Hardman-Mountford and McGlade 2002). The boundaries of currents are extremely important to fisheries. In divergences the deeper nutrient rich water is brought into the surface layers where it causes a higher production of organic matter and an accompanied concentration of fish. Likewise, the convergences cause dynamically a concentration of zooplankton and an accompanied concentration of fish (Hela and Laevastu 1961).

1.3 Distribution of grey triggerfish

The distribution of grey triggerfish is in both eastern and western parts of the Atlantic Ocean (Sazonov and Galaktionova 1987). There had been recordings of grey triggerfish from English waters (Dulčić *et al.* 1997), occurrences along Mediterranean Sea, Azores, Canary Islands (Lobel and Johannes 1980), Islands of Madeira and coast of West Africa to Angola (Svetovidov 1964, cited by Sazonov and Galaktionova 1987). The triggerfish distribution in the western Atlantic is from Nova Scotia to Argentina (Briggs 1958, cited by Moore 1967; Sazonov and Galaktionova 1987). Up to 1978 the *Balistes carolinensis* (cf. *B. capriscus*) had become an important element in the catches from Senegal to Nigeria, an ecosystem which used to be a biotope for sciaenid community was dominated by the *Balistes* in the late 1970s which formed about half of the total demersal biomass in the Gulf of Guinea (Longhurst and Pauly 1987, Koranteng *et al.* 1996). The species, *B. capriscus* has a very wide bathymetric distribution in Ghanaian coastal waters (MFRD 1993) which occurs at near the bottom as well as near the surface of the sea (usually 15 – 50 m depth).

There are reports that two separate stocks of grey triggerfish used to occur in the Gulf of Guinea (Stromme *et al.* 1982, Stromme 1983). The eastern stock which occurred off Ghana and the western stock, off Guinea Bissau and Guinea (see Fig. 1) (Stromme *et al.* 1982, Stromme 1983, Mensah and Quaatey 2002), both had almost disappeared. The biomass of the eastern stock was estimated to be 500 000 and 140 000 tons in 1981 and 1986 respectively (Stromme *et al.* 1982, Ofori-Adu 1994). It is reported that triggerfish species was at maximum abundance at the end of the 1970s in the Gulf of Guinea and at the beginning of the 1980s in the Canary current (Caverivière 1982, Stromme *et al.* 1982).

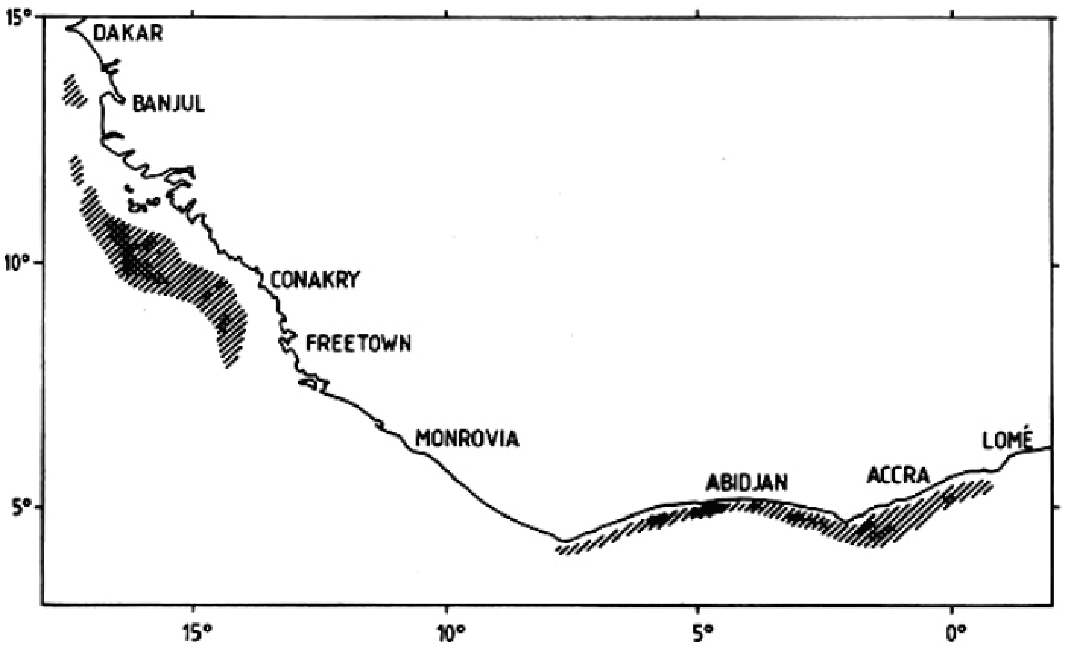


Fig. 1: Distribution of triggerfish in West Africa from acoustic observations in June 1981 Fridtjof Nansen survey showing the eastern and western stocks of triggerfish resource. (Source: Saetersdal *et al.* 1999)

1.4 Grey triggerfish fishery resource in Ghana

The estimated biomass of triggerfish in May, 1981-March, 1982 in Ghanaian coastal waters was between 314 000 and 500 000 tons (Stromme *et al*. 1982; Ofori-Adu 1987, 1994). It was indicated by Essuman and Diakité (1990) and Fishery Research Unit, FRU (1981) report that triggerfish was rated as one of the commercially valuable demersal fish in coastal waters of Ghana which contributed significantly to local food fish supply and the fishery improved income levels of artisanal fishermen and processors in many coastal towns and provided jobs for many people. There was management problem of triggerfish which was considered in 1987 as been under-exploited in Ghanaian coastal waters (Ofori-Adu 1987). The highest concentration of the species in Ghanaian coastal waters was located on the continental shelf off Takoradi (185 km), Elmina (230 km), Saltpond (270 km), Winneba (330 km) and Tema (415 km) (see Figs. 2 and 3) – these were fishery and meteorological stations alongshore with relatively wider continental shelf (Essuman and Diakité 1990; Ofori-Adu 1987, 1994). Based on the 1980-81 survey results on demersal fish species off Saltpond-Winneba (270-330 km) it was reported that there is no significant differences in catch rates of *B. capriscus* between Winneba and Saltpond waters (and among the depth ranges) eventhough there had been earlier notion that the species is most abundant between 30 and 50m depth range and also more abundant in the Saltpond area than that of Winneba (MFRD 1993). Falling catch rates had also been observed for *B. capriscus* beyond 50 m depth (FRU 1983). The species is caught by both the bottom trawl nets and purse seine nets (Essuman and Diakité 1990; Ofori-Adu 1987, 1994). Saltpond-Winneba survey in 1980-81 report showed the dominance of *B. capriscus* of the total catches of all other species both by weight and by numbers. The species contribution to the total catch was more than 60 % by weight and over 80 % by number in the thermocline (warm) season and about 48 % by weight of the total catch of all fish species caught in thermocline and upwelling seasons (MFRD 1993).

1.5 Biology of grey triggerfish

Marine Fishery Research reports indicate *Balistes* catch rates rise in September and reach maximum abundance in October to November in Ghana (FRU 1983; Essuman and Diakité 1990), which happens to be the spawning period of *B. capriscus*. These reports were corroborated in Ofori-Danson (1990) on the studies of reproductive ecology of *B. capriscus* in Ghanaian coastal waters. He proposed the spawning period of the species in Ghanaian coastal waters (based on annual maturation cycle and utilization of ovarian material) as three months from October to December, with the warm months – November and December - indicating intensive spawning activity (Ofori-Danson 1990).

Triggerfish is extremely resistant to the rigours of being trawled and its leathery skin slows dessication (Longhurst and Pauly 1987, Ofori-Adu 1987). The species *B. capriscus* show some preference for high temperature and low salinities (thermocline condition) in the Saltpond-Winneba area in Ghana (MFRD 1993). It is known that triggerfish is carnivorous as well as omnivorous (Ofori-Adu 1987, 1994). The species is basically a demersal fish which feeds mainly on benthic invertebrates like marine molluscs and crustaceans (Ofori-Danson 1981). Triggerfish also feeds on zooplankton such as amphipoda and copepoda. Zooplankton which usually dominate in Ghanaian coastal waters during upwelling periods are *Calanoides carinatus* (MFRD reports 1983, 1990; Binet and Marchal 1993). The presumed prey species of marine invertebrates abundant in Ghana and Gulf of Guinea waters include: Marine crabs (Brachyurans), Tropical spiny lobsters (*Panulirus* spp), Penaeus shrimps (*Penaeus* spp), Natantian decapods (*Natantia*), Cuttlefish (Sepiidae) and various squids (Loliginidae) (FAO 2006). Triggerfish is a nest-builder (Caverivière 1982, Longhurst and Pauly 1987), and exhibit parental care which includes tending and guarding of eggs against intruders occur not only in *Balistes capriscus* (Lobel and Johannes 1980) but also in other triggerfish species such as *Xanthichthys mento* (Kawase 2003) and *Sufflamen chrysopterus* (Ishihara and Kuwamura 1996). It is indicated in Essuman and Diakité (1990) that *Balistes capriscus* migrate from coastal waters during cold season to warmer waters further offshore which are usually between 25 °C - 26 °C (Houghton 1976) off Ghanaian coast. As to whether the migration of grey triggerfish to warm offshore waters is triggered by the sea temperature changes in coastal waters of Ghana or the species migrate to spawn in suitable temperature conditions is really difficult to ascertain from literature. However, other demersal spawners such as *Oxymonacanthus longirostris* (Monacanthidae) are able to shift spawning seasons until water temperatures are suitable for breeding (Kokita and Nakazono 2000), a characteristic which is not known in triggerfishes.

Ageing and growth of *Balistes capriscus* has been reported from various marine ecosystems including Gulf of Guinea. In all grey triggerfish ageing reports, first dorsal spines were used to age *B. capriscus*, for instance, in northeastern Gulf of Mexico (Johnson and Saloman 1984), in U.S. Virgin Islands and Puerto Rico (Manooch III and Drennon 1987), and in Ghana and West African waters (Ofori-Danson 1981, 1989). Growth parameters and natural mortality reports on grey triggerfish resource in coastal waters of Ghana is highlighted in Ofori-Danson (1981, 1989) and Koranteng (1998); and that of growth status of triggerfish resource from Côte d'Ivoire and Senegal waters (Caverivière 1982). West African region recorded below estimated potential yield of the grey triggerfish species in the 1980s for which it was concluded that the triggerfish resource was not over-exploited (Mensah and Quaatey 2002). Nevertheless, there were indications of grey triggerfish resource nearing over-exploitation in 1980 in the western Gulf of Guinea (see appendix, Fig. 32).

1.6 Objectives

General objectives:

- To analyse possible links between seasonal and interannual fluctuations of local environmental forcing and fluctuations of *Balistes capriscus* landings in coastal waters of Ghana.
- Assess the importance of overfishing in the collapse of *Balistes capriscus.*

Specific objectives

Objective 1:

- Reconstruction of extreme hydrographic events over the period 1974-2004 based on time series of SST, wind speed and salinity.

Objective 2:

- Assess a possible relationship between *Balistes* catch regime and environmental time series over the period 1974-2004.
- Assess a possible relationship between *Balistes* catch and fishing effort employed in the exploitation of the fishery resource.
- Assess a possible change of diet of *Balistes* due to the fishery collapse.

Objective 3:

- Assess exploitation rate of *Balistes capriscus* in Ghana (western Gulf of Guinea).

2 Materials and Methods

2.1 Environmental data acquisition and analysis

The daily sea surface temperature (SST) and beach salinity data used were from the Marine Fisheries Research Division (MFRD) of Ministry of Fisheries, formerly Department of Fisheries under Ministry of Food and Agriculture (MoFA) in Tema, Ghana. The SST and salinity raw data cover the period from 1974 to 2004, and eight recording stations spread along the Ghanaian coast (stations are located within approximately 1 km distance from the beach). Daily SST were recorded directly from the sea, and water samples were collected daily and sent to the MFRD laboratories for the analysis of salinity employing an inductive salinometer. The MFRD recording stations from west to east end of Ghana include: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km) (Figs. 2 and 3). Salinity records were incomplete in some stations and years (see Figs. 11 a-c). Between 1984 and 1995 salinity records were from Tema station; and in addition to Tema station there were records from Cape Three Points in 1990, and Keta in 1986 to 1988. The daily wind speed data used in this study were from Ghana Meteorological Agency. The wind speed raw data covers period between 1974 and 2004 which were recorded from six meteorological stations spread along the coastline of Ghana (usually coastal meteorological stations are sited few metres from the beach). The meteorological stations from west to east end of Ghana include: Axim (105 km), Takoradi (185 km), Saltpond (270 km), Accra (390 km), Tema (415 km) and Ada (490 km) (Figs. 2 and 3).
Normal upwelling occurs when the surface temperature reaches 25 °C and the intense cooling occurs when the surface temperature during cooling season reaches 22 °C in coastal waters of Ghana (FRU 1981, MFRD 1990).

Monthly means of SST, salinity and wind speed were calculated from the mean daily records. Detailed time series of mean monthly environmental data for each year were analysed using Ocean Data View (ODV) software 3.1.0 version (Schlitzer 2006) developed by Alfred

Wegner Institute (AWI), Bremerhaven - Germany. The ODV analyses were presented in three groups of periods for each environmental parameter: a) 1974-1985, b) 1986-1997, and c) 1998-2004. These period groupings were only convenient for representing the numerous ODV output figures for 31 year period.

Fig. 2: Map of Ghana coastline. Insert: Africa map showing coastline of western Gulf of Guinea

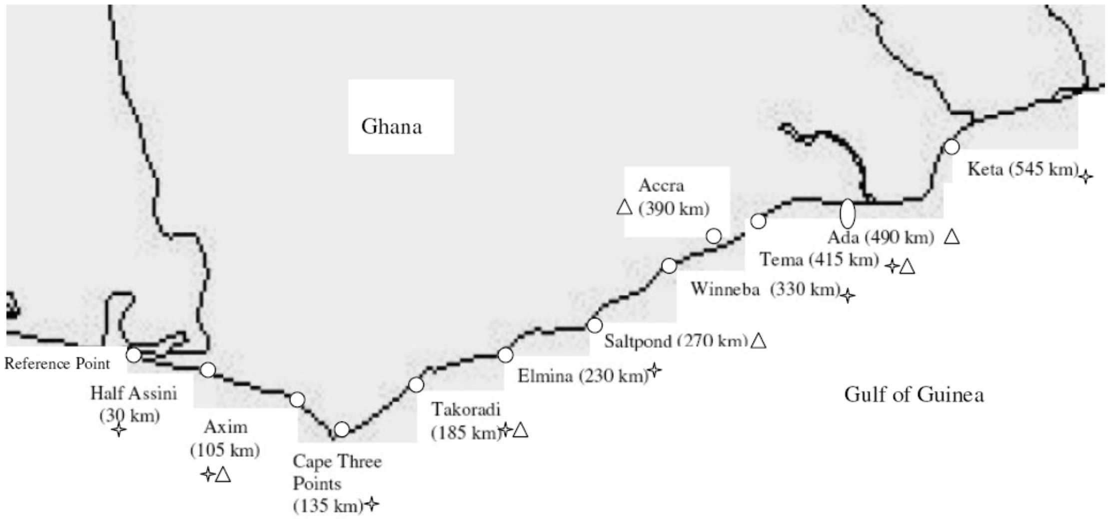


Fig. 3: Map of Ghana coast showing the climatic data collection stations. Distances from reference point to recording stations are shown along the coast of Ghana. +: Marine Fisheries Research Division recording station; Δ: Coastal Meteorological recording station

2.2 Catch and biological data acquisition

Annual catch data of Balistidae were obtained from Marine Fisheries Research Division formerly Fishery Research Unit (FRU), FAO and Fishbase (Froese and Pauly, 2006). Catch-effort data of inshore *Balistes* in coastal waters of Ghana between the period 1972 and 1991 were obtained from Koranteng (1998). Catch and biological data were collected for *Balistes* during "Dr. Fridtjof Nansen" survey 2005 in the western Gulf of Guinea. Total length (TL) in mm, body weight (W) in grams, sex (as male, female, intersexuals or undetermined) and maturity were recorded for each individual *Balistes* sampled. A total of 165 swept-area hauls were taken in Benin, Togo, Ghana and Côte d'Ivoire (western Gulf of Guinea) trawlable fishing grounds, between 20 and 100 m depth. Of the 165 trawls 27 were pelagic trawls and 138 were bottom trawls. 127 *Balistes* (*B. capriscus* and *B. punctatus*) were found in 23 of the hauls in depths ranging from 22 to 60 m. The specimens were collected fresh when they occurred in the hauls at various stations during the survey. Length, weight and other biological data such as gut and its contents of individual fish specimen were taken on-board immediately after the sample collection. First dorsal spines and otoliths were extracted from individual fresh fish, washed with water and stored dry in labelled sample bottles.

2.3 Inshore catch, effort and distribution of triggerfish

Inshore *Balistes* catch data were plotted against inshore effort over the period 1972-91 to ascertain periods *Balistes* biomass increased or decreased in coastal waters of Ghana. Catch-per-effort was also plotted against inshore effort over the period 1972-91. This was done to further ascertain the changes in the biomass of triggerfish in dominance and collapse periods. All the trawl hauls obtained during Fridtjof Nansen survey 2005 were plotted along the coast of Benin, Togo, Ghana and Côte d'Ivoire. The hauls that resulted in *Balistes* catch were shown as well as that of miscellaneous fish catches. Alongshore distances between the country borders along the western Gulf of Guinea were represented in km from Liberia- Côte d'Ivoire border to Benin-Nigeria border. Water depth ranges in western Gulf of Guinea were shown in metres from 50 m, 200 m and 1000 m. The number obtained for the two species of *Balistes* (*B. capriscus and B. punctatus*) were plotted against the actual capture depth and area the species were caught in a 3-dimensional space plot to assess the depth range of the two species of triggerfish. This might give some insight into change in habitat of *B. capriscus* and probably habitat overlap of the two sister species.

2.4 Relationships between temperature and triggerfish catch

Maxima mean daily temperature, minima mean daily temperature and difference between maximum and minimum mean daily temperature were related to the inshore *Balistes* catch over the period 1972-91. Each temperature maximum and minimum was obtained by averaging the daily temperature records for the months January to December from the eight MFRD recording stations along the coast of Ghana. The highest mean temperature for a particular year was taken as the temperature maximum and the lowest temperature for that year was taken as the temperature minimum. The difference between temperature maximum and minimum for various years were then computed. These exercises were done to find a possible relationship between *Balistes* catch regime and sea temperature in coastal waters of Ghana. It was also to identify the extreme temperature conditions under which *Balistes* catch had changed over the years.

Fig. 4: Image of *Balistes capriscus* (Grey triggerfish), TL 36.5 cm

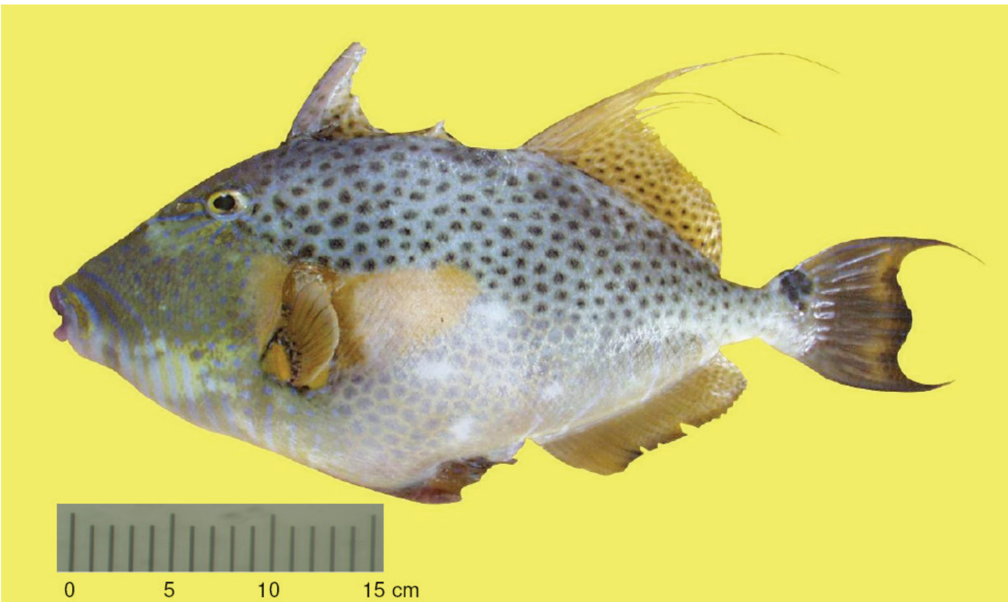
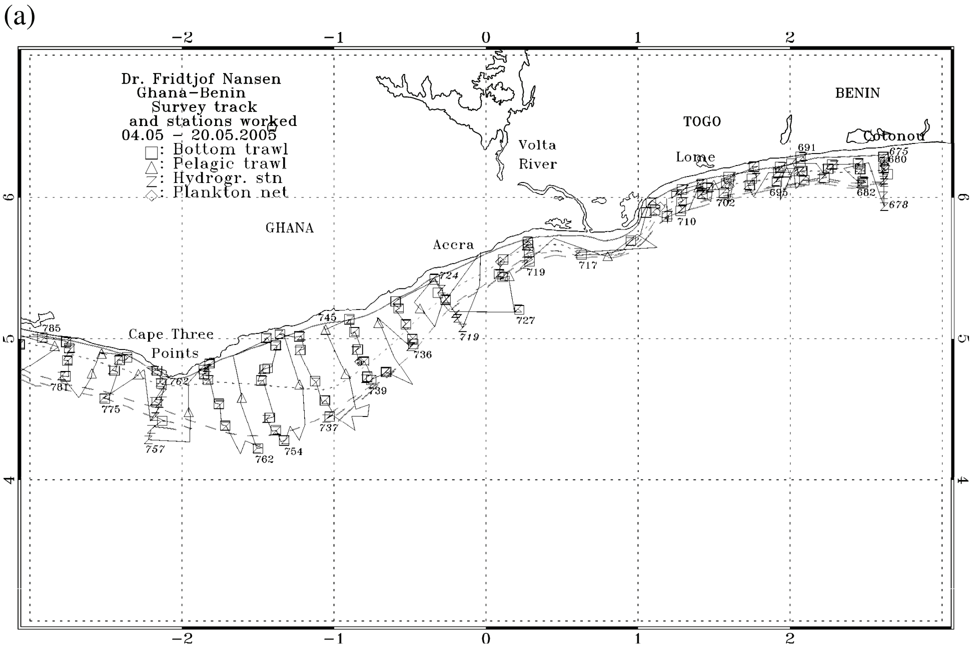


Fig. 5: Image of *Balistes punctatus* (Blue-spotted triggerfish), TL 40.0 cm

(a)



(b)

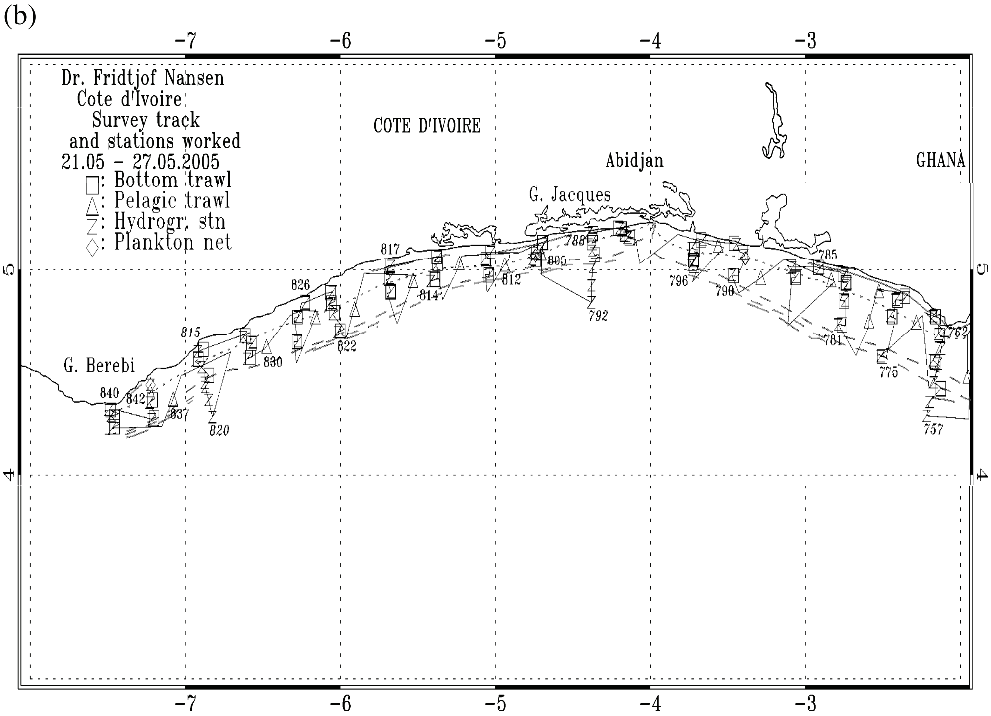


Fig. 6: Cruise course with fishing, plankton and hydrographic stations for a) Benin - Ghana and b) Ghana - Côte d’Ivoire. Depth contours at 20 m, 50 m, 100 m, 200 m and 500 m are indicated (source: Nansen survey 2005)

2.5 Growth studies

2.5.1 *Dorsal spine preparations and image analysis*

Thin sections (1 mm) of dorsal spines of *Balistes* were cut with a diamond-edged blade (Isomet® 4000-linear precision saw) at low speed through the centre in a transverse plane perpendicular to the long axis of the spine (Fig. 7). Three successive sections were obtained, the first section just above the condyle (the enlarge base of the spine), second section in the middle portion and the third section towards the anterior tip of the spine. Preliminary trials showed that transverse sections of spines from the middle towards the condyle produced much clearer increments than did sections towards the anterior portion. Spine sections were mounted on a glass microscope slide with a resin.

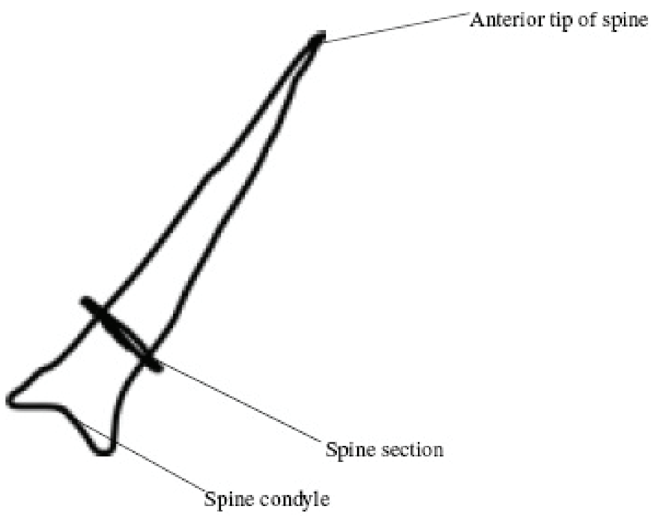


Fig. 7: Image of first dorsal spine of triggerfish indicating midway spine section

With a digital camera (Canon ESO) attached to a light microscope at low magnification (50x) slide image was captured and image analyser (Image-Pro® Plus 5.1 software) was used to count annuli and measure radii. Annuli counting were done on the best radius of a stitched-complete spine image. When the increment pattern was not clear, a prominent increment was followed laterally to the closest clear increment sequence. Where annuli were not clear to read image filters were used to enhance clarity.

2.5.2 *Growth rings interpretation*

Ages of individuals were determined by interpreting growth rings on sections of the spines. To determine the reading method, a sub-sample of 30 individuals was studied, interpreting growth rings on spine sections. Each spine section was read independently three times for reliable estimates of total number of annuli. Only light or translucent bands were counted as annuli in accordance with the validation of translucent bands (Johnson and Saloman 1984). A marginal light band was counted as full annulus but a marginal dark band was ignored in the counting of rings. Measurements were made from the focus to the posterior distal edge to represent spine radius, as well as the total length of the cross-section of the spine image (Fig. 8).

Due to insufficient numbers of *Balistes* (74 *Balistes capriscus* and 41 *B. punctatus*) the data for length-at-age was pooled for Benin, Togo, Ghana and Côte d'Ivoire samples based on the knowledge that they are part of the eastern triggerfish stock (Stromme *et al*. 1982, Stromme 1983, Mensah and Quaatey 2002) of the Gulf of Guinea.

Fig. 8: Image of spine showing growth rings and spine radius (from focus to posterior distal edge)

2.5.3 *Growth investigations*

Estimates of theoretical growth in length were obtained by fitting the observed length at age data to the standard form of von Bertalanffy growth equation (using FiSAT programme):

$L_t = L_\infty [1 - \exp‹-K(t-t_0)›]$

where L_t is the total length at age t, L_∞ the asymptotic length, K the growth coefficient, and t_0 the theoretical age at zero length.

The essence of the growth investigations were to find out possible change in growth in *Balistes capriscus* in the period of dominance, early 1980s (Caverivière 1982, Ofori-Danson 1981), and the period of disappearance, 1988 to date (this study).

2.5.4 *Back-calculation*

Back-calculation of the length-age data was carried out to further explore the *Balistes* growth data to obtain better growth parameters (L_∞ and K) from the von Bertalanffy Growth Model. The back-calculation of total lengths at various annuli was obtained by substituting the mean annulus radius into the total length-spine radius relationship. The estimated lengths at annulus were averaged to give the weighted mean or back-calculated total length at that annulus.

2.5.5 *Growth performance*

The growth performance of triggerfish (*Balistes capriscus* and *B. punctatus*) populations in terms of length was compared using the index of Pauly and Munro (1984):

$$\phi' = \log_{10} K + 2 \log_{10} L_\infty$$

where ϕ' is the growth performance index. The index is used to compare growth of the fish species for different time periods (dominance and collapse periods in the case of triggerfish in western Gulf of Guinea). Reported values of K and L_∞ obtained in various studies in the Gulf of Guinea in 1980s (Caverivière 1982; Ofori-Danson 1989) were used to calculate ϕ' for comparison with the estimates in this study.

2.6 Diet analysis

Diet analysis of triggerfish in this study was done to ascertain the possible changes in diet or food source of triggerfish that might have occurred during the collapsed period of the species in Ghanaian coastal waters as compared to the results of the diet analysis on *Balistes capriscus* in 1980 during the abundance period (Ofori-Danson 1981). The stomach contents of 115 triggerfish were studied using frequency of occurrence and gravimetric methods (Hyslop 1980). Specimens were obtained during Fridtjof Nansen survey 2005. The guts of individual triggerfish were removed and preserved in 10 % formalin for analysis. The food items were identified as far as possible (at least to the family level) using identification manuals such as Newell and Newell 1977; Gibbons 2000; Ruppert and Barnes 1994, Boltovskoy 1999. Stomach contents were weighed to the nearest 0.001 g. Few drops of water were added to stomach contents when they were clumped together for easy separation of food items in the petri dish. Weights were determined for various groups of food items. Empty stomachs were noted and recorded. Percent frequency of occurrence and percent gravimetric composition of food items were derived.

The numerical method was not considered in the data analysis due to the difficulty in counting the fragments of food items that occurred in the diet. In the case of *Balistes capriscus*, specimens were grouped in size (*TL* cm) class interval of 9.9 cm as follows: 12.0-21.9, 22.0-31.9, 32.0-41.9, 42.0-52.0 cm in the same *TL* classes as in the size distribution analysis of triggerfish. The number of fish gut specimens in each size class was at least 10 except size class 42.0-52.0 cm which was eight in number.
The size groupings of *Balistes punctatus* were the same as that of *B. capriscus* except the size class 42.0-52.0 cm which did not occur in the fish specimens. The number of *B. punctatus* gut specimens in size class 12.0-21.9 cm was five, that of 22.0-31.9 cm was 35 and that of 32.0-41.9 cm was only four.

Again, catches of the presumed prey or dominate groups of diet of triggerfish from 1978-2003 were extracted from FAO statistical reports on Ghana (FAO 1983, 1986, 1996, and 2006).

The capture records of the presumed prey of triggerfish in Ghanaian coastal waters were compared to the triggerfish catches over the period 1972-2003 to ascertain the influence of the main diet groups of triggerfish on the *Balistes* catch regimes. That is to say, the presumed diet (various marine crustaceans and mollusc) of *Balistes* abundant in Ghanaian waters were compared to the *Balistes* catch fluctuations to assess the effect on prey availability since the disappearance of the fish species.

2.7 Mortality and rate of exploitation

The natural mortality rate (M) was estimated from the empirical formula developed by Pauly 1980 as follows:

$$\log_{10} M = -0.0066 - 0.279\log_{10} L_{\infty} + 0.6543\log_{10} K + 0.4634\log_{10} T$$

where M is natural mortality, L_{∞} (TL) is expressed in cm, K is the rate of growth of fish and T is the mean annual environmental temperature (here taken as 22.0 °C for cooler periods and 25.0 °C for normal periods in Ghanaian coastal waters). The T °C used in this study was 22 °C based on the idea that the M calculated for *B. capriscus* in Koranteng (1998) using Ofori-Danson (1981, 1989) growth parameters on the species in coastal waters of Ghana was set at T = 20 °C. And since the current growth studies on *B. capriscus* in the collapsed period were being compared to that of the abundant period the author found it wise to use the cooler environmental temperature threshold of 22°C (FRU 1981) in coastal waters of Ghana to compute the M from Pauly's equation.

Again, the estimates of M values using mean temperature of T = 26.5 °C in coastal waters of Ghana from 1974-2004 were carried out to compare natural mortality using growth parameters in this study. This is the usual way of calculating M from Pauly's equation (that is, T from mean environmental temperature) and it was done in order to verify the observation that M in many cases (this study) was higher than Z.

Alternatively, natural mortality (*M*) was derived from Rikhter and Efanov's method to compare *M* estimated from Pauly's natural mortality method. The comparison of *M* was done to obtain better value for natural mortality for estimation of fishing mortality and subsequent exploitation ratio of *Balistes capriscus* resource in the western Gulf of Guinea.

Rikhter-Efanov relation is as follows:

$$M = [1.52/(t_{mass})^{0.72}] – 0.16$$

where t_{mass} is the age (in years) at massive maturation. In this study, t_{mass} is deduced from Ofori-Danson (1990) as *Balistes capriscus* of size range 145-200 mm *FL* which corresponds to 230-250 mm *TL* of *Balistes capriscus* in this study. This size of fish estimated corresponds to 4 - 5 years approximately.

The instantaneous rate of total mortality (*Z*) was estimated using length-converted catch curve model (FiSAT programme, Pauly 1983a) with *B. capriscus* catch data (sample size total of 84 in size distribution) obtained in Fridtjof Nansen survey 2005 where:

Ln (*N/ dt*) is plotted against relative age (years).

Ln(*N*) denotes the logarithm of length frequency and *t* denotes age.

Following estimation of *Z* and *M*, the fishing mortality (*F*) rate was calculated from $F = Z – M$, and the exploitation ratio $E = F/Z$ was then computed (Pauly 1983b; Jones 1984; Morales-Nin and Moranta 1997). The *E* in this study was compared to the exploitation ratio ($E = 0.67$) during the dominance period (early 1980s) of *Balistes capriscus* resource in western Gulf of Guinea.

2.7.1 *F, M and Z in collapsed fisheries scenario*

The mortality equation:

$$F + M = Z$$

where *F* denotes fishing mortality, *M* denotes natural mortality and *Z* denotes total mortality.

This relationship was reconsidered in the collapsed fisheries scenario where $F = 0$, or $F \approx 0$. The reason was that the triggerfish resource has disappeared and at present there is almost negligible fishing activity on the resource which renders *F* to be zero. For this reason, the mortality equation was reconsidered in the collapsed triggerfish scenario.

3 Results

3.1 Seasonal fluctuations in environmental parameters and triggerfish catch

The time series plots in Figs. 9 - 11 consists of recording stations (km), time (months) and sea temperature (°C), wind speed (m/s) or salinity. Each graph shows plots of an environmental parameter averaged from daily records for each month (over the seasonal period from January to December) along the coast of Ghana. Each station distance indicated on the plots represents the approximate distance measured from the western tip of Ghana (ie. the boundary between Cote d'Ivoire and Ghana or reference point) to the recording station along the coast (Fig. 3). The environmental parameter scales are standardized as follows: each SST plot ranges from 17.0 to 31.5 °C (Figs.9 a-c), wind speed plot 1.0-12.0 m/s (Figs. 10 a-c) and salinity plot 24.0-38.0 (Figs. 11 a-c). In each plot, the blue colour region indicates low levels and yellow-red colour region indicates high levels of an environmental parameter. In the case of sea temperature, the intensity of blue colour indicates the intensity of cooling along the coast of Ghana. In the case of wind speed, the yellow and/or red portions indicate areas of high coastal winds and the blue portions are the areas of low wind speeds. Yellow and red portions in the salinity plots indicate areas of high salinity and blue portions are the low salinity areas.

A detailed time series analysis of the SST data indicates two cooling cells along the coast of Ghana (Figs. 9 a-c). One cell occurs in the west coast usually intensive off Half Assini (30 km) – Takoradi (185 km) waters (termed west-coast major cooling cell), whereas the other cell occurs at the east coast usually intensive off Winneba (330 km) - Keta (545 km) waters (termed east-coast major cooling cell). From the SST plots, the cooling during the major upwelling usually starts in May and ends in October but intensified in July-September. The duration of cooling along the coast of Ghana varies from year to year. There are seasons that have extended cooling periods and other seasons with short duration of cooling along the coast of Ghana. In 1976, 1977, 1978, 1980, 1981, 1991 and 1995 seasons, the intense cooling (blue cell) concentrated at the west coast; and that of 1982, 1983 and 2004 occurred mainly at the east coast. In 1975, 1984, 1985, 1986, 1988-1990, 1992-1994 and 1997-2003 intense cooling were recorded on both sides of the coast. The sea temperatures recorded were unusually high in 1979 and 1987 and therefore the cooling intensities were minimal along the coast. The sea temperature plots of 1974, 1983, 1984, 1988-1990, 1996, 1998, 1999, 2003 and 2004 show intrusion of high temperatures during minor cooling period. Sea temperature range in the period 1974-2004 was 17.23 - 31.12 °C.

A detailed time series (ODV) analysis of wind data indicates two main wind speed sections along the coast of Ghana (Figs. 10 a-c).
These sections include:

i. west coast wind [WCW] section, which is, low speed range(1.0 – 4.0 m/s); and
ii. east coast wind [ECW] section, which is, high speed range (4.5 – 12.0 m/s).

Two separate cells of high speed wind in WCW section were identified in this study from 2001 to 2004 at Takoradi (185 km) coastline. The meeting zone of ECW and WCW usually occurred at the Saltpond (270 km) – Winneba (330 km) coastline suggesting occurrence of an ocean front in this area. Occasionally, the meeting zone occurred closer to either Takoradi or Accra (390 km) – Tema (415 km) coastline (Figs. 10 a-c). The wind plots in 1974-1979, 1983-84, 1986-89, 2000 and 2004 indicate strong wind fields along the east coast which usually occurred along Accra-Tema coastline. The strong wind fields along east coast are identified in both minor and major cooling periods. In 1976, 1977, 1979, 1986, 1988-90 and 2000 wind plots indicate weaker wind fields during the minor cooling period than during the major cooling period. In 1983, 1986 and 2004 the strong wind fields at the east coast extended to further-east towards Togo waters. Coastal wind speed range in the period 1974-2004 was 1.1 - 12.0 m/s.

Detailed time series analysis of salinity data indicated that low salinities occurred at the west coast of Ghana (usually Half Assini -30 km, Axim -105 km and Cape Three Points -135 km) between May-June and August-September. The low salinity conditions were extended to November-December in 1974, 1979 and 1980-1982. Coastal salinities on the east coast of Ghana generally remained high (Figs. 11 a-c). There are indications of low salinities during the minor cooling season at the east coast in 1981, 1985, 1994, 1997, 1998, 2000 and 2002-2004. Coastal salinity range in the period 1974-2004 was 25.1 – 38.0.

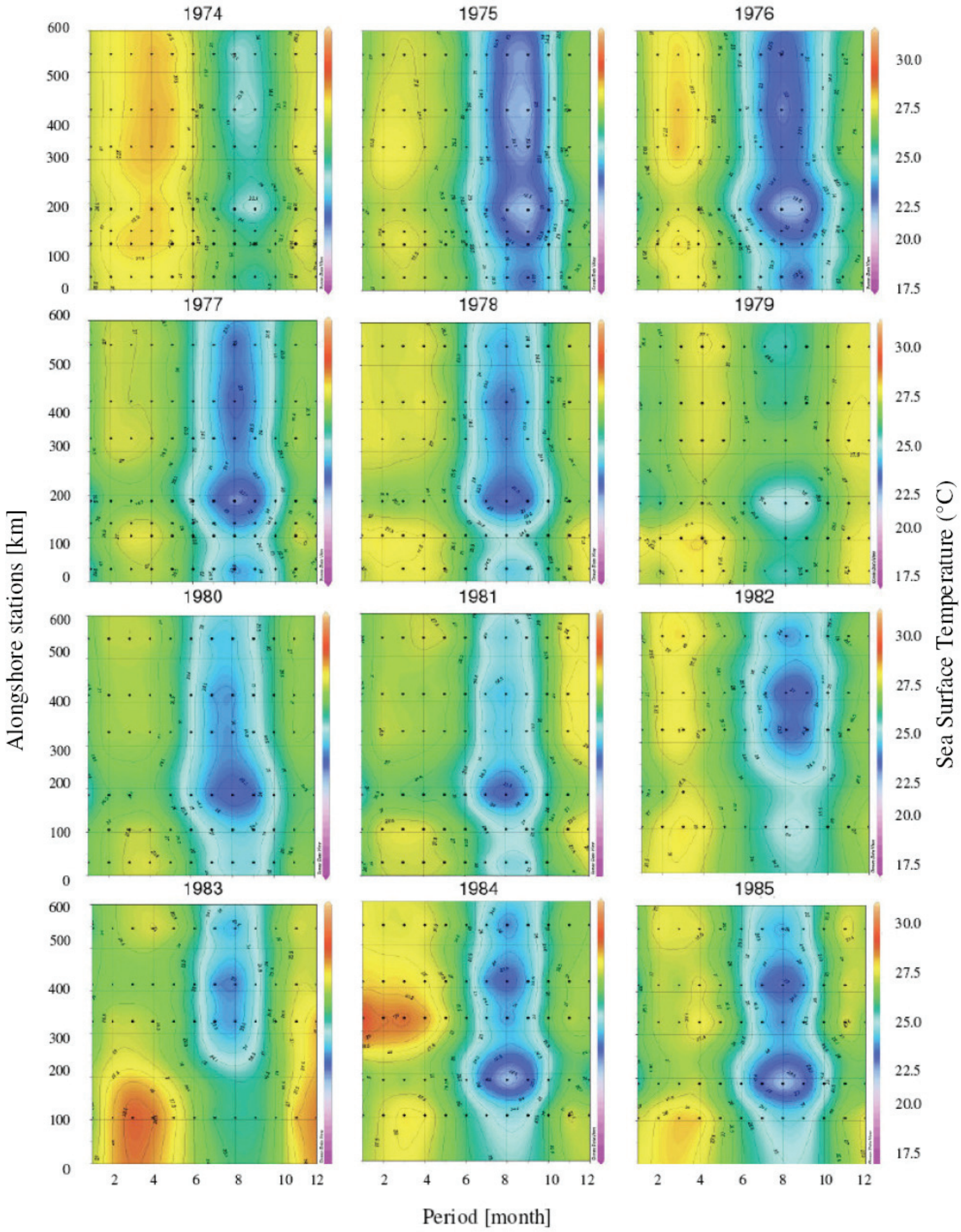


Fig. 9-a: ODV analyses of monthly mean SST in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). SST range: 17.23 °C – 31.12 °C

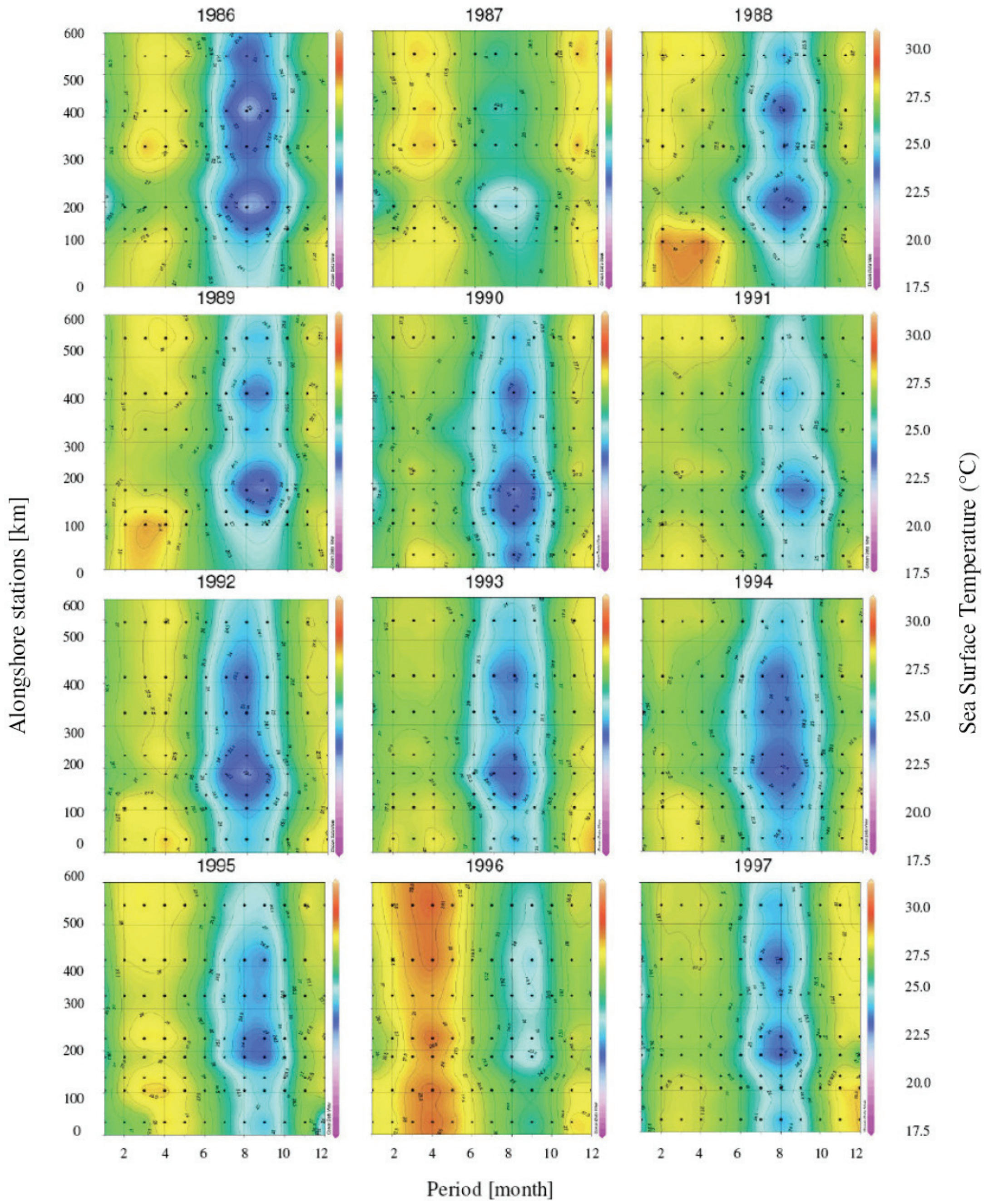


Fig. 9-b: ODV analyses of monthly mean SST in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). SST range: 17.23 °C – 31.12 °C

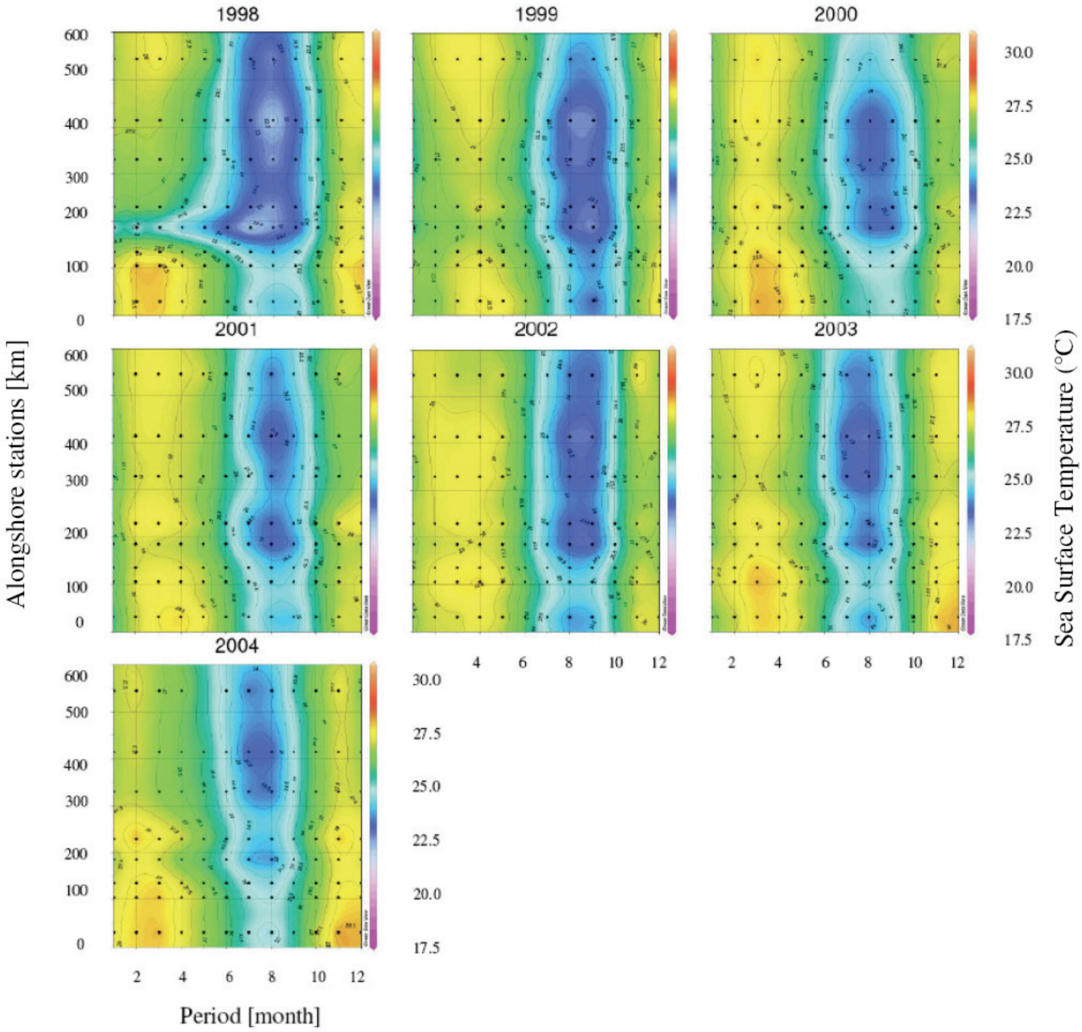


Fig. 9-c: ODV analyses of monthly mean SST in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). SST range: 17.23 °C – 31.12 °C

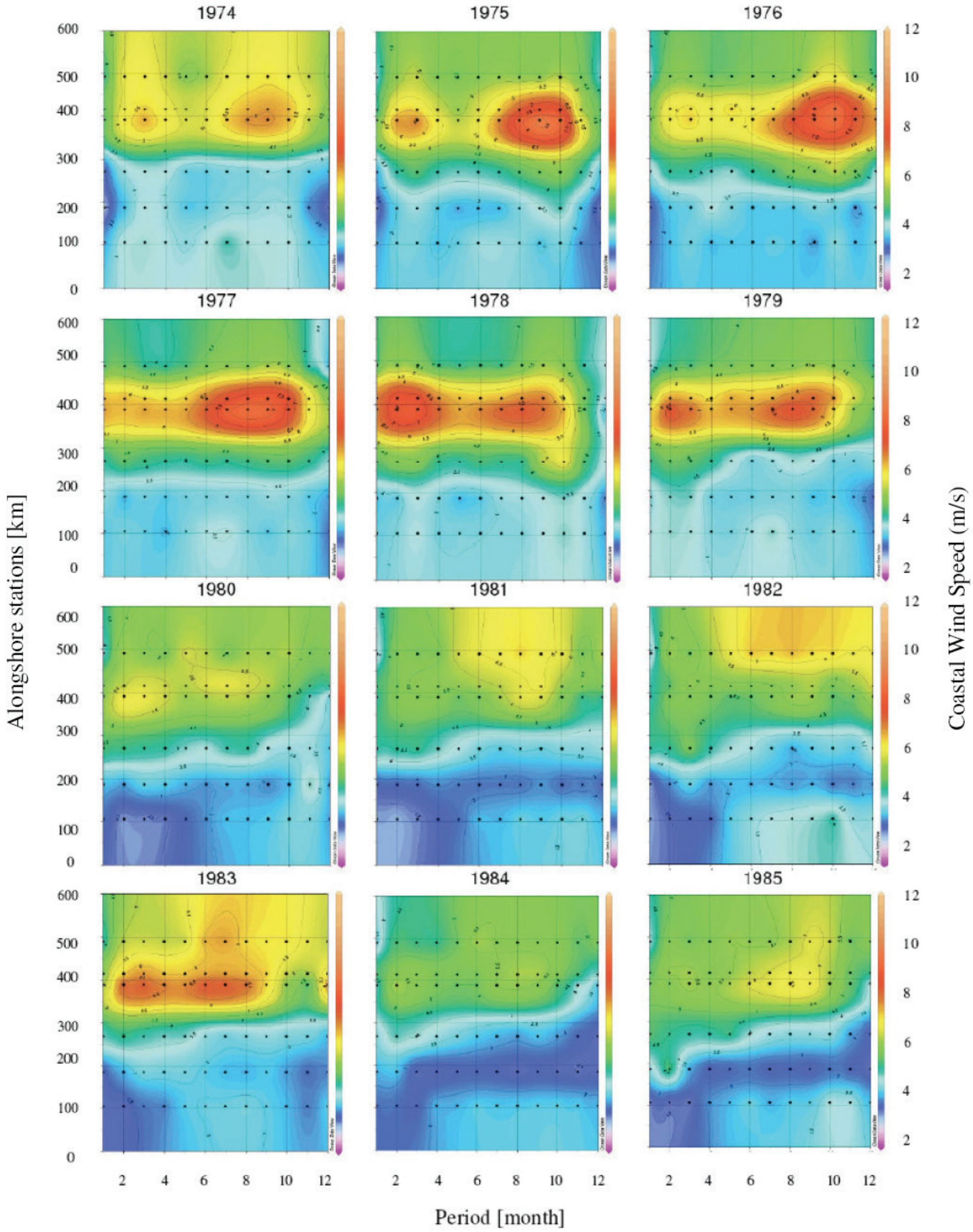


Fig. 10-a: ODV analyses of monthly mean wind speed along the coast of Ghana. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore meteorological stations: Axim (105 km), Takoradi (185 km), Saltpond (270 km), Accra (390 km), Tema (415 km) and Ada (490 km). Coastal wind speed range: 1.1 m/s – 12.0 m/s

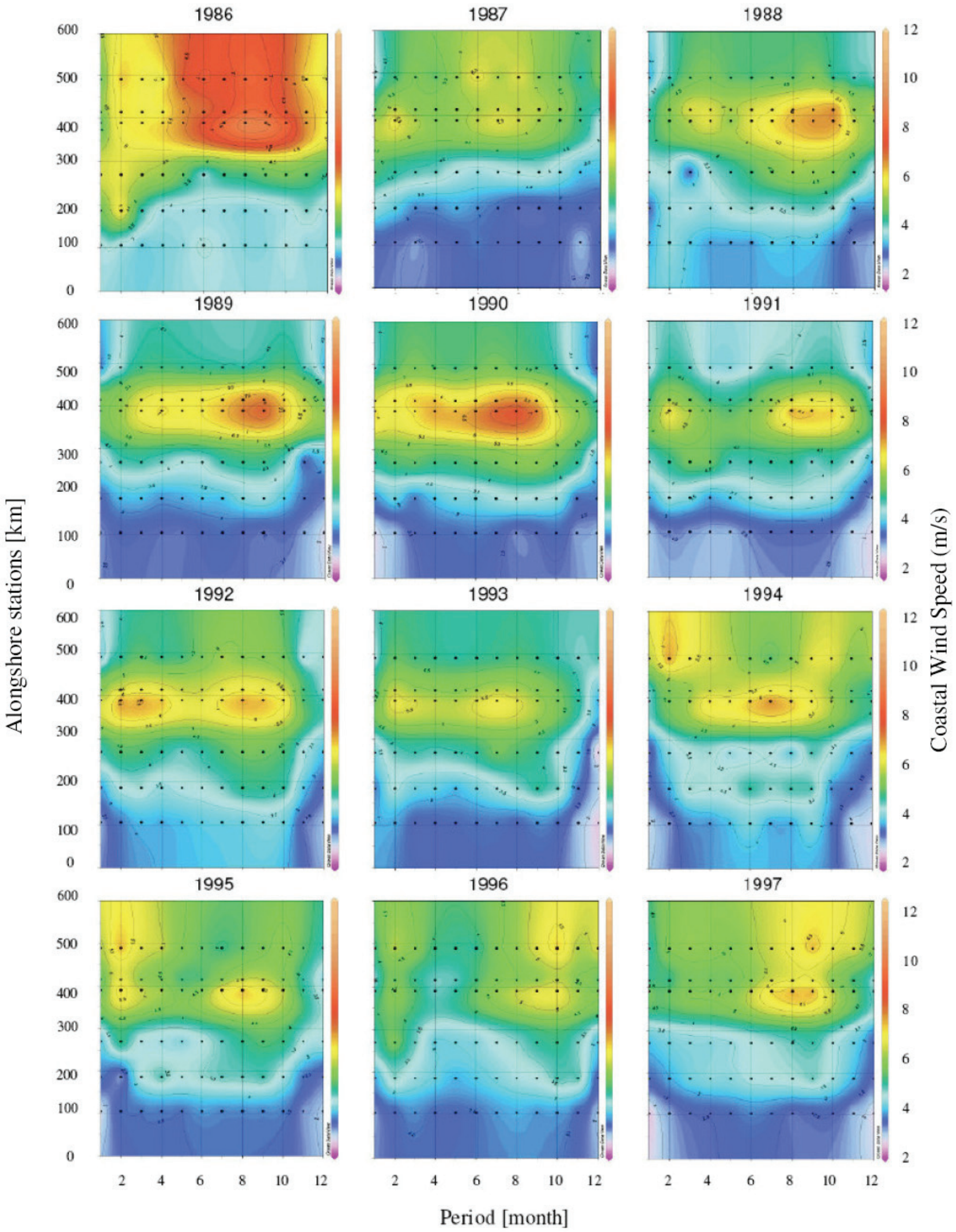


Fig. 10-b: ODV analyses of monthly mean wind speed along the coast of Ghana. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore meteorological stations: Axim (105 km), Takoradi (185 km), Saltpond (270 km), Accra (390 km), Tema (415 km) and Ada (490 km). Coastal wind speed range: 1.1 m/s – 12.0 m/s

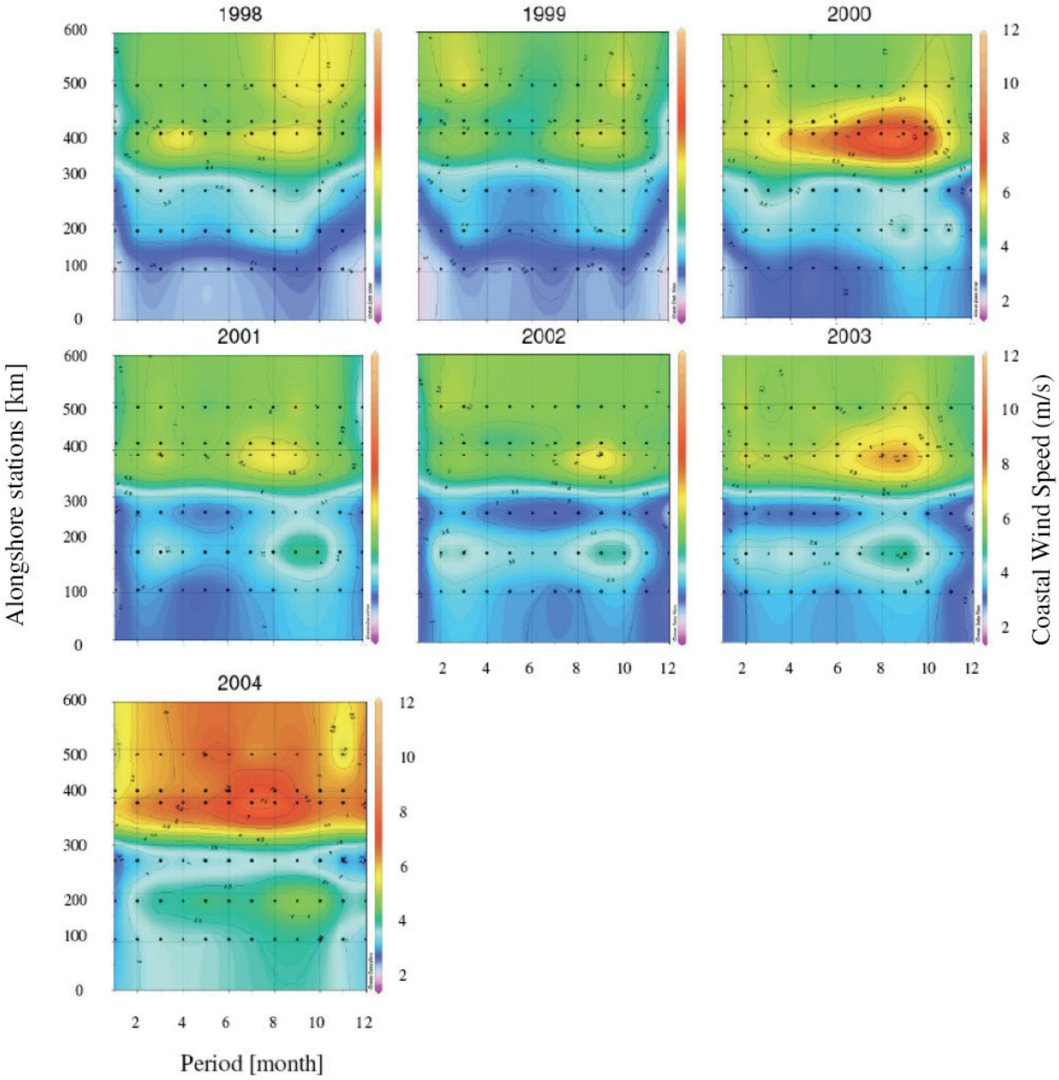


Fig. 10-c: ODV analyses of monthly mean wind speed along the coast of Ghana. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. Alongshore meteorological stations: Axim (105 km), Takoradi (185 km), Saltpond (270 km), Accra (390 km), Tema (415 km) and Ada (490 km). Coastal wind speed range:
1.1 m/s – 12.0 m/s

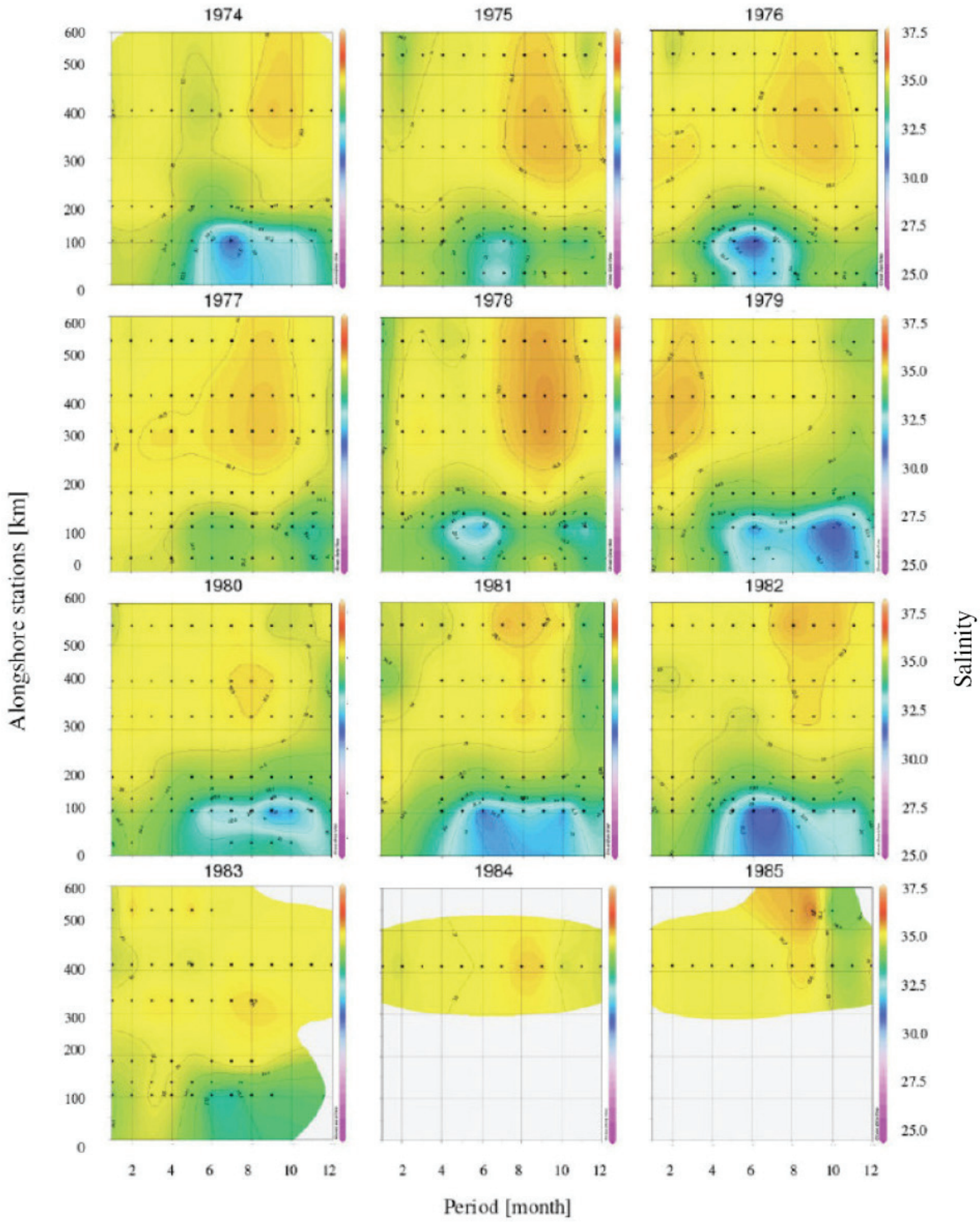


Fig. 11-a: ODV analyses of monthly mean salinity in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. White portions indicate stations with missing data. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). Salinity range: 25.1 - 38.0

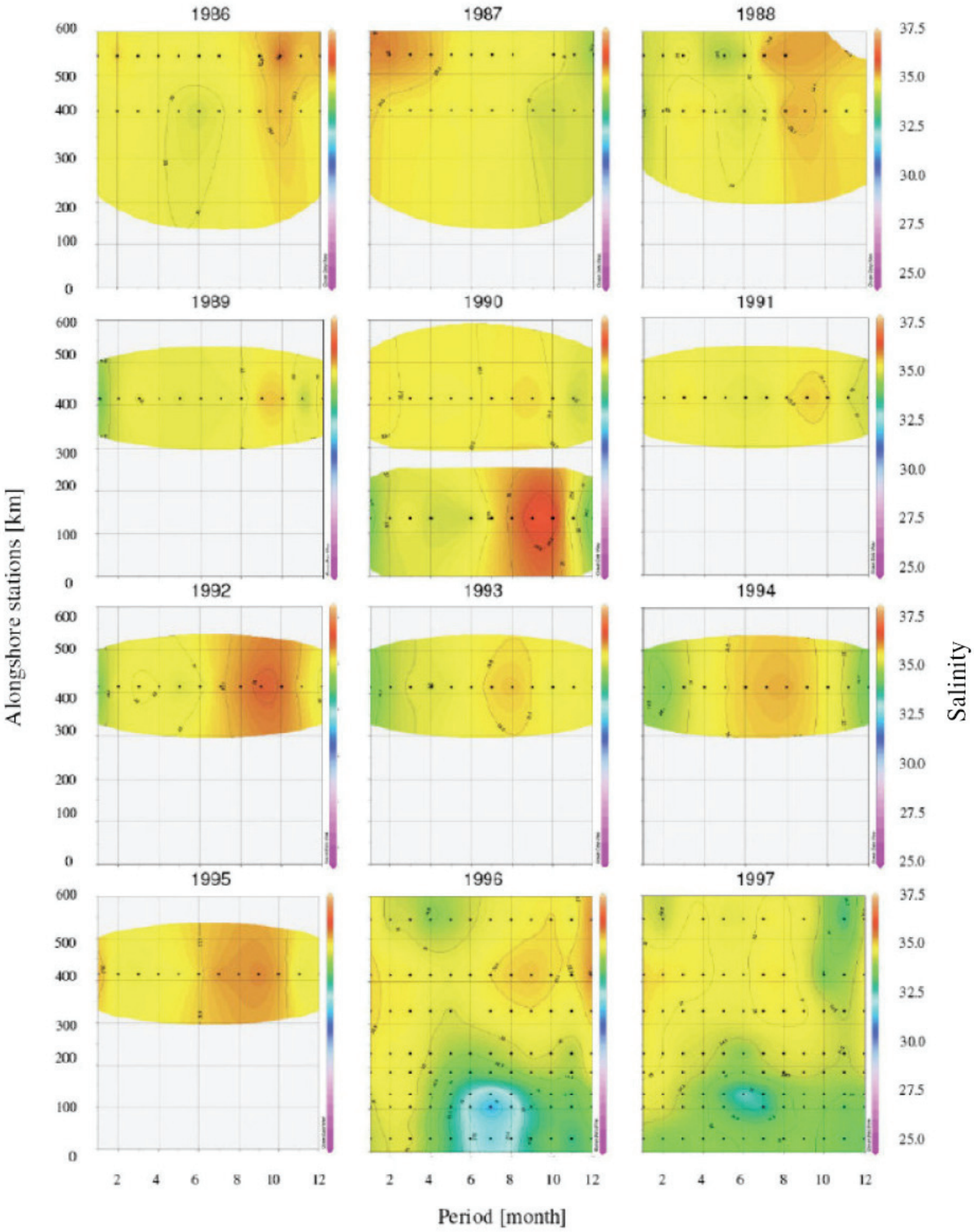


Fig. 11-b: ODV analyses of monthly mean salinity in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. White portions indicate stations with missing data. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). Salinity range: 25.1 - 38.0

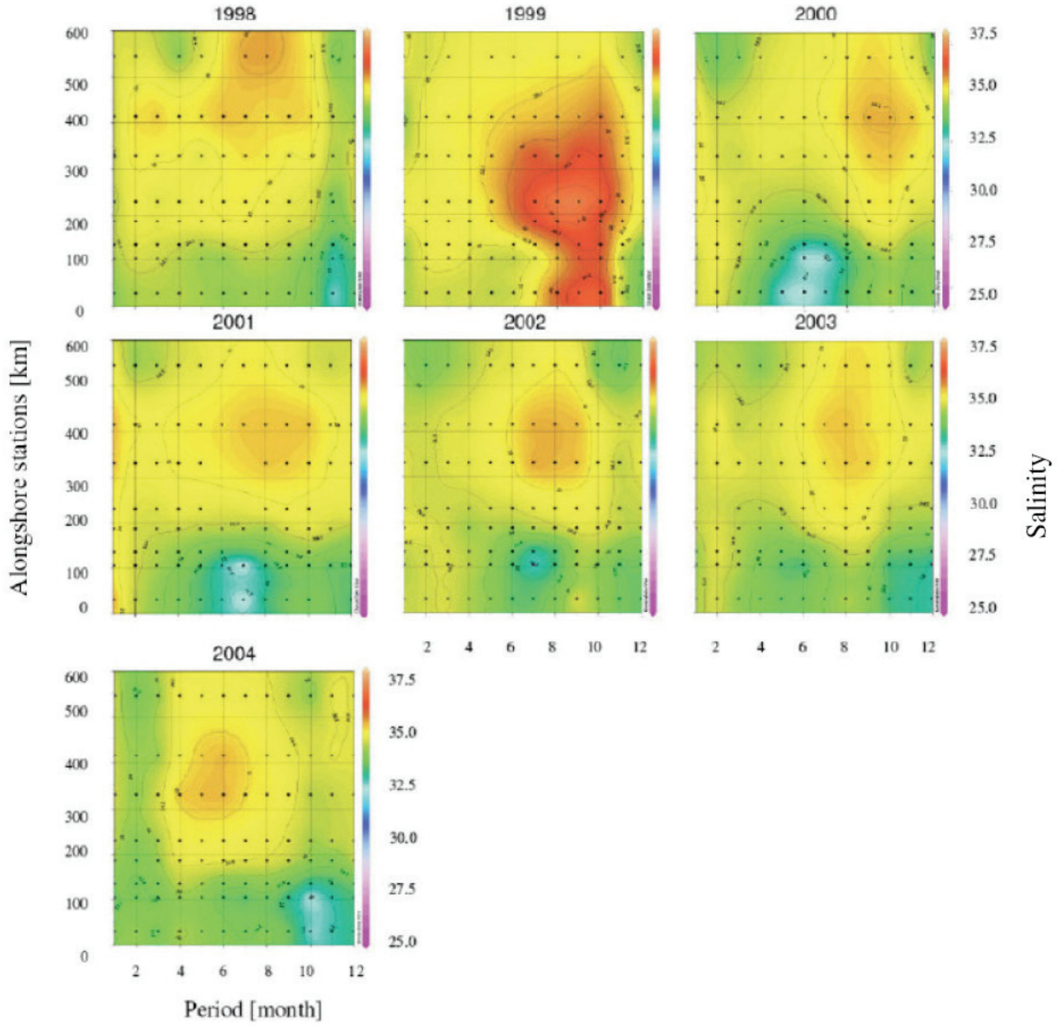


Fig. 11-c: ODV analyses of monthly mean salinity in Ghanaian coastal waters. Each monthly mean is averaged from daily records over the period January 1974 to December 2004. White portions indicate stations with missing data. Alongshore stations: Half Assini (30 km), Axim (105 km), Cape Three Points (135 km), Takoradi (185 km), Elmina (230 km), Winneba (330 km), Tema (415 km) and Keta (545 km). Salinity range: 25.1 - 38.0

3.2 Catch and distribution of triggerfish

Fig. 12 shows the annual triggerfish landings in Ghanaian coastal waters from 1972-2003. The annual catches of triggerfish show two separate peaks between 1972 and 2003. The first catch peak (12 563 tons) occurred in 1979, and the second peak (17 250 tons) in 1986/87 (Fig. 12). Before 1979, triggerfish catch levels were from 2 830 tons (1972) to 9 138 tons (1977). In between 1979 and 1986/87, triggerfish catch fell to ‘regular or stable’ annual levels (5 000 – 8 000 tons / year). After 1987, triggerfish catch experienced a ‘sharp’ decline in 1988 to 2 862 tons which continued to decline up till to date (Fig. 12).

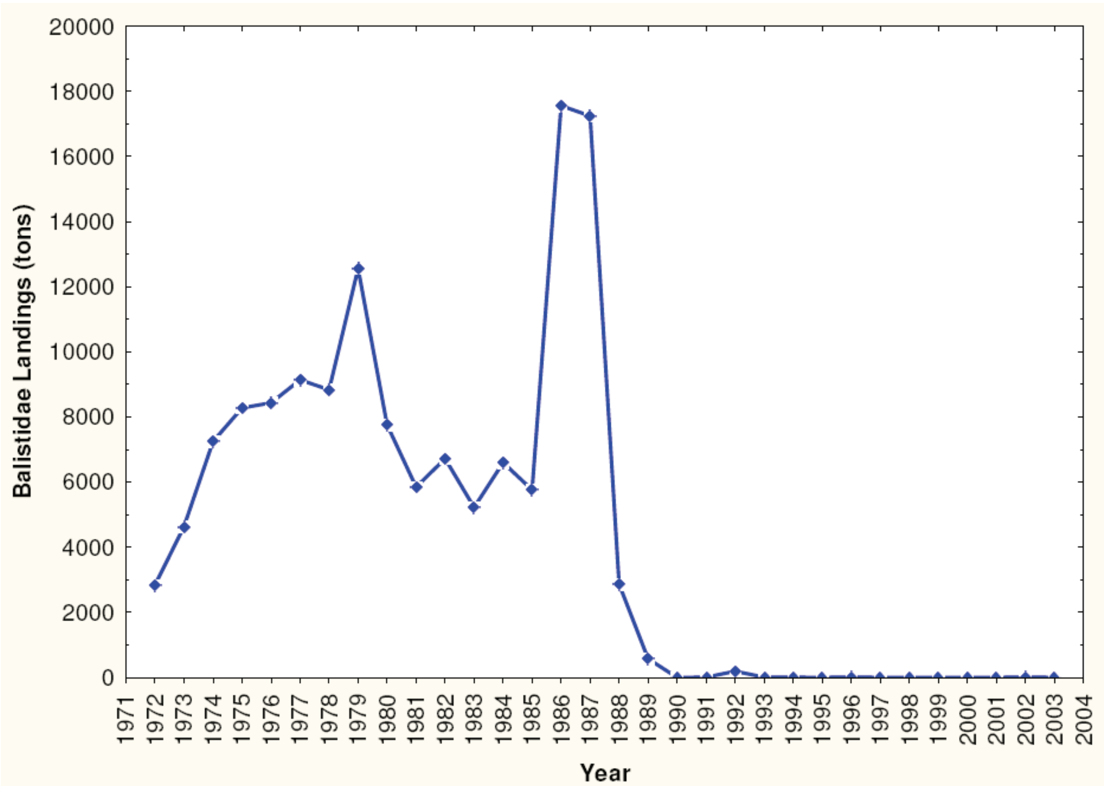


Fig. 12: Catches of Balistidae (Triggerfish) in Ghanaian waters (landing data from FISHBASE- Froese and Pauly, 2006 & FAO Statistics)

Considering the catch-effort relationship from 1972-91 (Fig. 13) of inshore triggerfish data extracted from Koranteng (1998) indicate that inshore triggerfish catch generally increase with inshore effort (indicated by curve A). There was increase of inshore triggerfish catch from 1972-79. Figure 13 shows that inshore effort from 1972-75 (green arrow B) was virtually the same eventhough inshore triggerfish catch was then on the ascendancy from 2847 - 8170 tons for the period. There was decrease in effort in 1975-77 with slight decline in catch but inshore triggerfish catch attained 9 752 tons in 1979 when the first catch peak was realized. Inshore catch decreased dramatically from 1979-80 (red arrow C) at relatively the same effort and since then effort had continuously decreased from 1980-84 (that is, 12865 to 5002 operations) with approximately the same catch levels of 5273 in 1980 to 3402 in 1984. Catch increased again in 1984-86 (green arrow D) at increased effort. Inshore catch decreased progressively with effort from 1987-91 indicated by red arrows E and F (see Fig. 13).

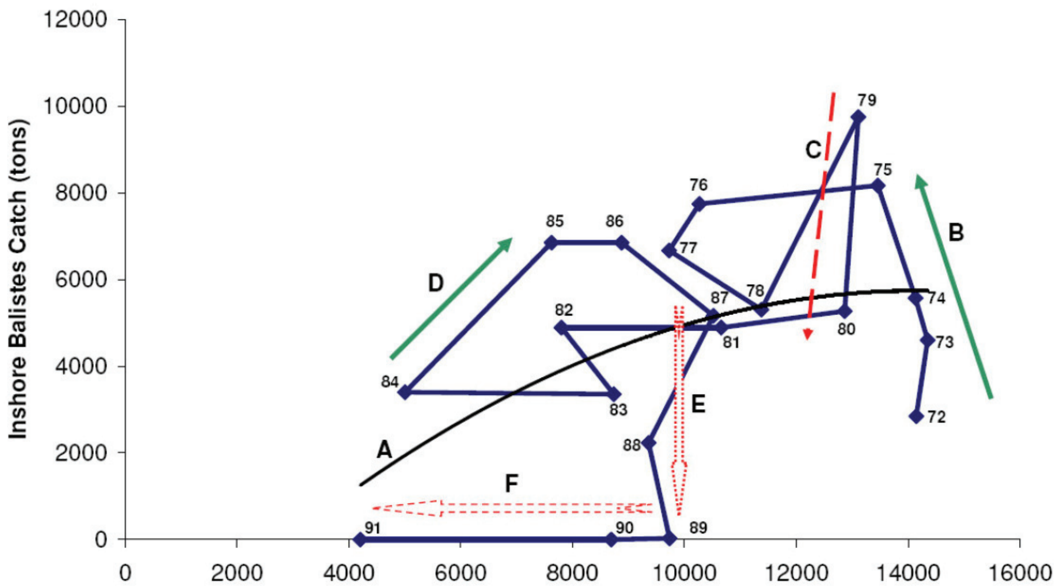


Fig. 13: Inshore catch versus effort of *Balistes* in Ghana from 1972-1991 (Data source: Koranteng 1998). The plots from 72 to 91 represent the period (year) from 1972-91. Solid green arrows (B and D) pointing upwards indicate scenarios where catch increased; broken red arrows (C and E) pointing downwards indicate scenarios where catch decreased at virtually the same inshore operations or number of trips (effort)

The inshore catch-per-effort and effort relationship is shown in Fig. 14. The figure shows that there was increased biomass at almost the same effort from 1972-76 indicated by solid green arrows. The triggerfish biomass decreased drastically from 1979-80 at virtually the same effort indicated by broken blue arrow. Between 1981 and 1984 inshore effort decreased with slight change in catch-per-effort. The triggerfish biomass was highest in 1985 and decreased afterwards up to 1991 indicated by broken red arrows. The biomass decrease was quite significant from 1987-89 at virtually the same effort; and 1989-91 there was virtually no biomass of the triggerfish resource in Ghanaian coastal waters (Fig. 14).

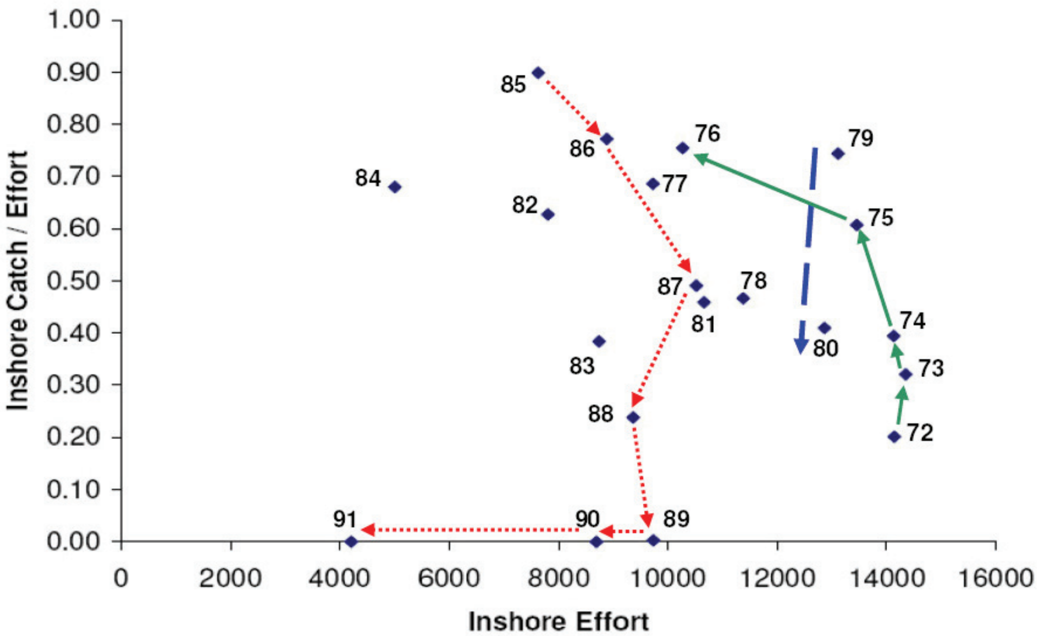


Fig. 14: Inshore catch per effort versus effort of *Balistes* in Ghana from 1972-91. The plots from 72 to 91 represent the year period from 1972-91. The solid green arrows pointing upwards indicate increase in biomass; and broken red arrows pointing downwards indicate decrease in biomass at virtually the same effort

Fig. 15 shows the distribution of triggerfish that were caught in the western Gulf of Guinea during Fridtjof Nansen survery 2005. Both species of triggerfish (*B. capriscus and B. punctatus*) occurred from Benin waters through Togo and Ghana to Côte d'Ivoire. The round plots indicate the stations where the hauls resulted in *Balistes capriscus*; the diamond plots indicate the locations where *Balistes punctatus* were caught; and the cross plots represents other stations for which miscellaneous fish species were caught other than triggerfish (Fig. 15). In all 165 stations were trawled along the western Gulf of Guinea from Liberia-Côte d'Ivoire border to Benin-Nigeria border. Of the 165 station trawls 23 hauls yielded triggerfish which include: 8 stations in Côte d'Ivoire of which one station recorded both *B. capriscus* and *B. punctatus*, 8 stations in Ghana, 6 stations in Togo and 1 station in Benin of which both *B. capriscus* and *B. punctatus* were obtained. Of 165 total trawl stations 54 trawls were done between Liberia-Côte d'Ivoire and Côte d'Ivoire-Ghana borders which consists of 10 pelagic trawls (PT) and 44 bottom trawls (BT); 77 trawls were carried out between Côte d'Ivoire-Ghana and Ghana-Togo borders which comprise 13 PT and 64 BT; 12 trawls were done between Ghana-Togo and Togo-Benin borders which consists of 2 PT and 10 BT; 22 trawls were carried out between Togo-Benin and Benin-Nigeria borders which comprise 2 PT and 20 BT (see Fig. 15). The main pelagics obtained in the miscellaneous trawl stations include: clupeids, carangids, scombrids, hairtails and barracudas. The miscellaneaous trawl stations recorded valuable demersals such as seabreams, snappers, groupers, grunts and croakers. Alongshore distance from west end (Liberia-Côte d'Ivoire border) to the east end (Benin-Nigeria border) which covers the stretch of 1 237 km is indicated. The figure also shows the depth ranges of 50 m, 200 m and 1000 m offshore. The triggerfish capture depth range was from 22-60 m depth during the survey period.

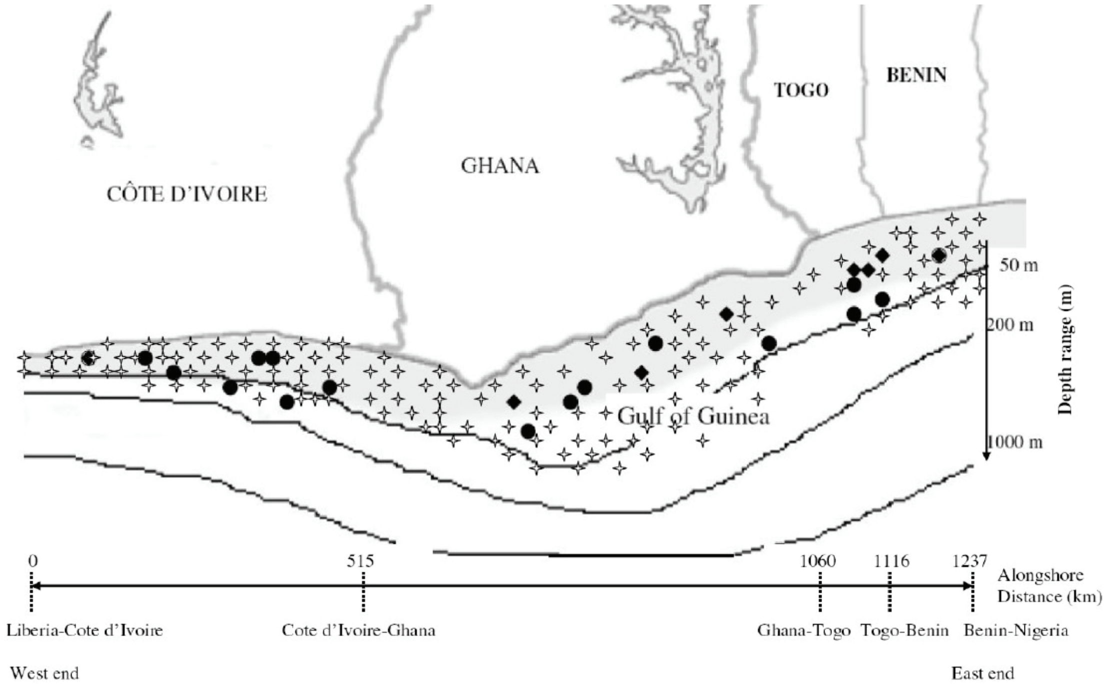


Fig. 15: Distribution of triggerfish in western Gulf of Guinea in May 2005 (●: stations with *Balistes capriscus* catch; ♦: stations with *Balistes punctatus* catch; +: stations with miscellaneous fish catch other than triggerfish). Offshore depths are 50 m, 200 m and 1000 m. Alongshore distance is 1 237 km from west to east ends

Fig. 16 shows the capture depth range of *Balistes* caught during Fridtjof Nansen survey 2005 in the western Gulf of Guinea. The area the fish were caught are represented by distance (km) and the number of *Balistes* obtained in each area are indicated. The figure gives detailed information on the distribution of *B. capriscus* and *B. punctatus* in western Gulf of Guinea. It shows that both species of triggerfish were caught from Côte d'Ivoire to Benin waters (see Fig. 16). In Côte d'Ivoire waters, 46 triggerfish were caught at eight different stations with depth range of 23 to 60 m. In Ghana, 30 triggerfish were caught at 8 different stations between 25 and 47 m depth range. In Togo, 41 triggerfish were caught at 6 different stations with depth range of 22 to 52 m; whereas 10 triggerfish were caught in Benin waters at 32 m depth in one station. *B. punctatus* were found in coastal waters between 22 to 32 m depth range in the western Gulf of Guinea; whereas *B. capriscus* were caught in waters between 23 to 60 m depth range from Côte d'Ivoire to Benin. The highest number of *B. punctatus* (26) was caught off Togo at the depth of 23 m; and the highest number of *B. capriscus* (26) was caught off Cote d'Ivoire at the depth of 36 m (Fig. 16).

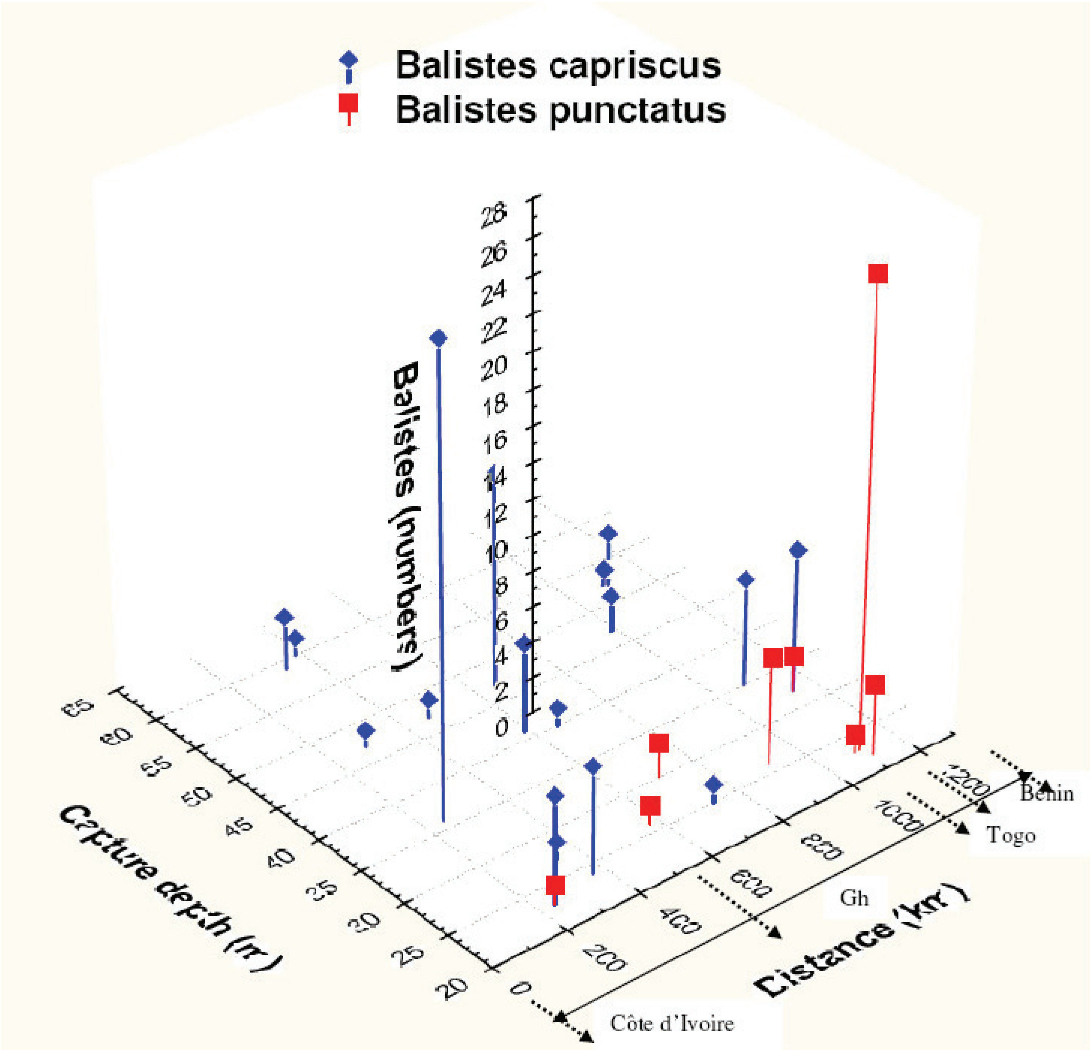


Fig. 16: Distribution, capture depth and *Balistes* caught in western Gulf of Guinea in May 2005. Countries bordering western Gulf of Guinea are shown

3.3 Relationships between sea temperature and inshore triggerfish catch

The inshore catch of *Balistes* was related to maximum mean daily temperature, minimum mean daily temperature, and difference in maximum and minimum mean daily temperatures (ie. Tmax-Tmin) over the period 1972-91 in Fig. 17 below. In addition, two possibilities of *Balistes* spawning and recruitment periods were explored in Fig. 17 based on the knowledge of the biology of the species.

In Fig. 17, inshore catch of *Balistes* was plotted against (A): maximum mean daily temperature, (B): minimum mean daily temperature, and (C): difference in maximum and minimum mean daily temperatures (ie. Tmax-Tmin).
In (A) temperature partitioning (Tp) is identified in between the periods *Balistes* catch or biomass increased with maximum temperature recorded (1972-76); and periods *Balistes* catch decreased with rising maximum temperature recorded (1985-89) in coastal waters of Ghana. A critical maximum mean temperature (Tc) is identified in 1987 (Tc = 28.72 °C) beyond which *Balistes* declined up to virtually zero biomass in 1989. In addition, there was catch increase from 2 847 tons in 1972 to 5 572 tons in 1974 at temperature range from 27.91 °C in 1972 to 28.39 °C in 1974. The catch decreased tremendously from 9 752 tons in 1979 to 5 273 tons in 1980 at temperature range of 28.10 °C in 1979 to 28.21 °C in 1980. Again, catch decreased greatly from 5 167 tons in 1987 to 2 229 tons in 1988 at temperature range of 28.72 °C in 1987 to 29.09 °C in 1988.

In (B) no Tp and Tc of minimum mean temperatures were identified. Again, there was catch or biomass increase from 2 847 tons in 1972 to 5 572 tons in 1974 at temperature range from 21.86 °C in 1972 to 22.96 °C in 1974 indicated by solid black arrow. The catch decreased tremendously from 9 752 tons in 1979 to 5 273 tons in 1980 at temperature range of 24.18 °C in 1979 to 23.20 °C in 1980 indicated by broken blue arrow. Again, catch decreased greatly from 5 167 tons in 1987 to 2 229 tons in 1988 at temperature range of 24.54 °C in 1987 to 22.33 °C in 1988.

At (C) no Tp and Tc of difference in temperatures (Tmax-Tmin) were identified. Again, there was catch or biomass increase from 2 847 tons in 1972 to 5 572 tons in 1974 at Tmax-Tmin range from 6.06 °C in 1972 to 5.43 °C in 1974 indicated by solid black arrow. The catch decreased tremendously from 9 752 tons in 1979 to 5 273 tons in 1980 at Tmax-Tmin range of 3.92 °C in 1979 to 5.01 °C in 1980 indicated by broken blue arrow. Similarly, catch decreased greatly from 5 167 tons in 1987 to 2 229 tons in 1988 at Tmax-Tmin range of 4.18 °C in 1987 to 6.76 °C in 1988.

In addition to Fig. 17 (B), if *Balistes* spawned successfully in 1974 at minimum mean temperature of 22.96 °C the stock would have been recruited in 1979 where the first catch peak occurred (Fig. 12). Again, if spawning was successful in 1983 at minimum mean temperature of 22.76 °C the stock would have been recruited in 1987 where the second catch peak was realized (Fig. 12). Similarly in Fig. 17 (B), if *Balistes* spawned successfully in 1975 at lower minimum mean temperature of 21.45 °C the fish stock would have been recruited in 1979 (first catch peak); and successful spawning in 1982 at lower minimum mean temperature of 21.81 °C the fish stock would have been recruited in 1987 (second catch peak).

In Fig. 17 (C), if *Balistes* spawned successfully in 1974 at temperature difference (Tmax-Tmin) of 5.43 °C the fish stock would have been recruited in 1979 (first catch peak); and if spawning was successful in 1983 at Tmax-Tmin of 4.92 °C the fish stock would have been recruited in 1987 (second catch peak). Similarly in Fig. 17 (C), if *Balistes* spawned successfully in 1975 at higher temperature difference of 6.59 °C the fish stock would have been recruited in 1979; whereas a successful spawning in 1982 at higher temperature difference of 6.82 °C the fish stock would have been recruited in 1987.

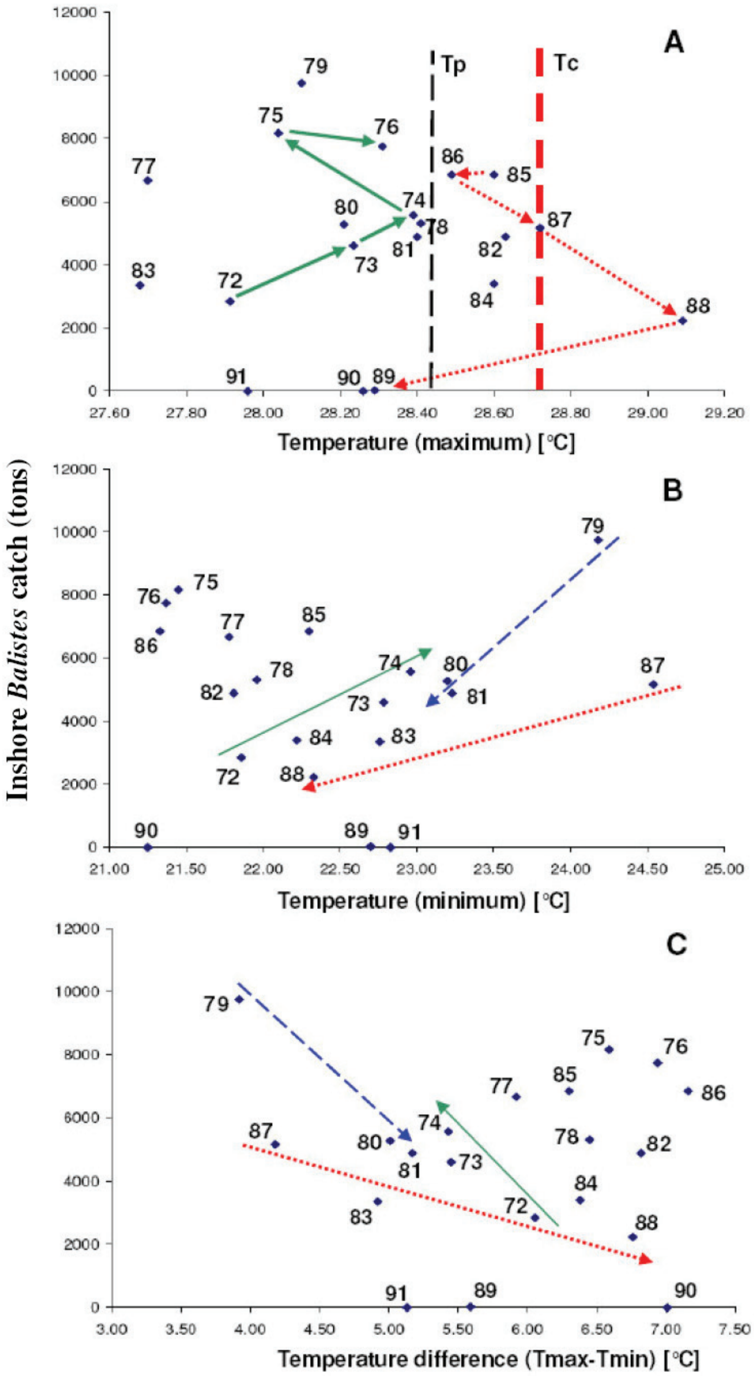


Fig. 17: Inshore *Balistes* catch versus temperature in coastal waters of Ghana. Plots indicate years from 1972-91. (A) Solid green arrows pointing upwards indicate increase in catch at temperature (maximum) range; Tp: temperature partitioning; Tc: critical temperature. (B) Broken arrows pointing downwards indicate catch decrease, solid arrow pointing upwards indicates catch increase at temperature (minimum) range. (C) Broken arrows pointing downwards indicate catch decrease, solid arrow pointing upwards indicates catch increase at temperature difference (Tmax-Tmin) range

Temperature ranges at which inshore *Balistes* biomass increased (1972-74) and decreased (1979-80 and 1987-88) in Ghana are shown in Table 2. In the period 1972-74, there was increased maximum temperature (A) but the range (0.48 °C) was narrow. There was moderately increased minimum temperature (B) range of 1.10 °C, and narrowly decreased Tmax-Tmin (C) range of 0.63 °C. In 1979-80, there was narrowly decreased maximum temperature (A) range of 0.11 °C; moderately decreased minimum temperature (B) range of 0.98 °C; and moderately decreased Tmax-Tmin (C) range of 1.09 °C. In 1987-88, there was narrowly decreased maximum temperature (A) range of 0.37 °C; widely decreased minimum temperature (B) range of 2.21 °C; and widely increased Tmax-Tmin (C) range of 2.58 °C in Ghanaian coastal waters.

Table 2: Temperature ranges at which *Balistes* biomass increase from 1972-74, and biomass decrease from 1979-80 and from 1987-88 in coastal waters of Ghana (see Fig. 17). Temperature range in bracket, increase or decrease indicated

	Temperature range (°C)		
	1972-74	**1979-80**	**1987-88**
(A)Temperature (maximum)	narrow, increase (0.48)	narrow, decrease (0.11)	narrow, decrease (0.37)
(B)Temperature (minimum)	moderate, increase (1.10)	moderate, decrease (0.98)	wide decrease (2.21)
(C)Tmax-Tmin	narrow, decrease (0.63)	moderate, increase (1.09)	wide increase (2.58)

3.4 Growth and ageing of triggerfish

3.4.1 *Size distribution of triggerfish*

Figs. 18 and 19 show size distribution of triggerfish species caught during the Fridtjof Nansen survey May 2005 in the western Gulf of Guinea. In the case of grey triggerfish the modal size classes were 27.0 – 31.9 cm and 32.0 – 36.9 cm where 21 of the fish specimens were obtained in each class. The size class of 52.0 – 56.9 cm was the less dominant in the catches of grey triggerfish (Fig. 18). The modal size class of blue-spotted triggerfish was 27.0 – 31.9 cm where 18 of the specimens were obtained. The size class of 37.0 – 41.9 cm was one of the less dominant size groups represented in the catches of blue-spotted triggerfish (Fig. 19). There were bigger sizes of grey triggerfish obtained in the catches than that of blue-spotted triggerfish.

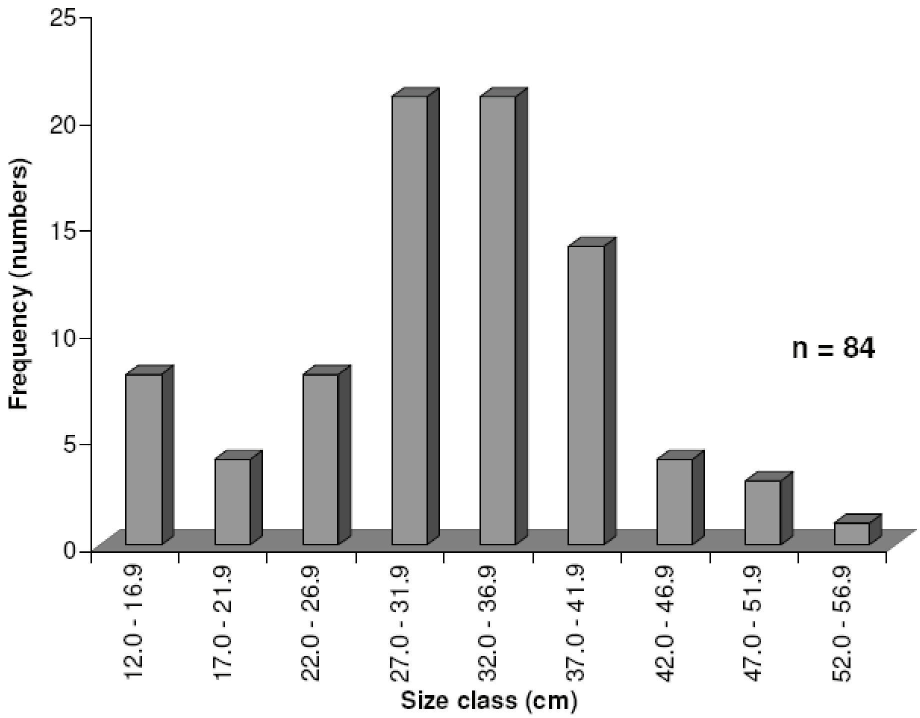


Fig. 18: Size distribution of grey triggerfish in western Gulf of Guinea, May 2005

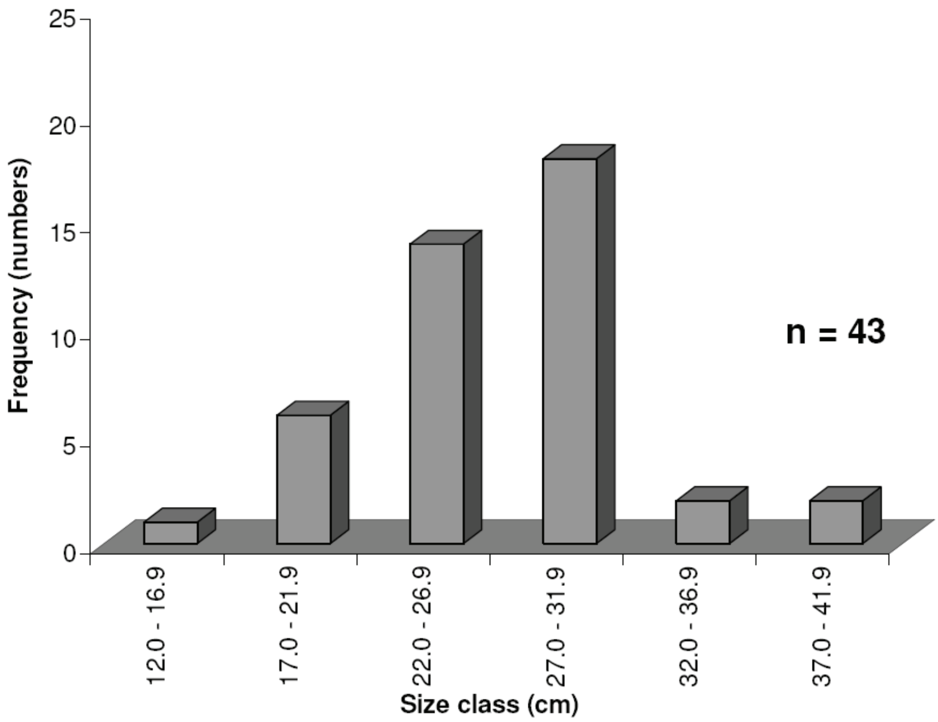


Fig. 19: Size distribution of blue-spotted triggerfish in western Gulf of Guinea, May 2005

3.4.2 *Size-weight relationships*

Figs. 20 and 21 are the size-weight graphs of *Balistes capriscus* (grey triggerfish) and *B. punctatus* (blue-spotted triggerfish) in the western Gulf of Guinea. The size-total weight relationships showed a good fit to the exponential curve (R^2 = 0.9835) and (R^2 = 0.9805) for *B. capriscus* and *B. punctatus* respectively (Figs. 20 and 21). The calculated parameters were:

$W = 0.0711\ L^{2.515}$ (*Balistes capriscus*)

$W = 0.0415\ L^{2.7838}$ (*Balistes punctatus*) where L is total length (cm) and W is total body weight in grams. In Fig. 20, the size and weight range of *B. capriscus* were 12.7-52.0 cm and 36.8-1268.5 g respectively. The size and weight range of *B. punctatus* were 16.0-40.0 cm and 90.2-1042.5 g respectively (Fig. 21). The growth in weight was allometrically positive in both species (as the exponent of length is close to 3).

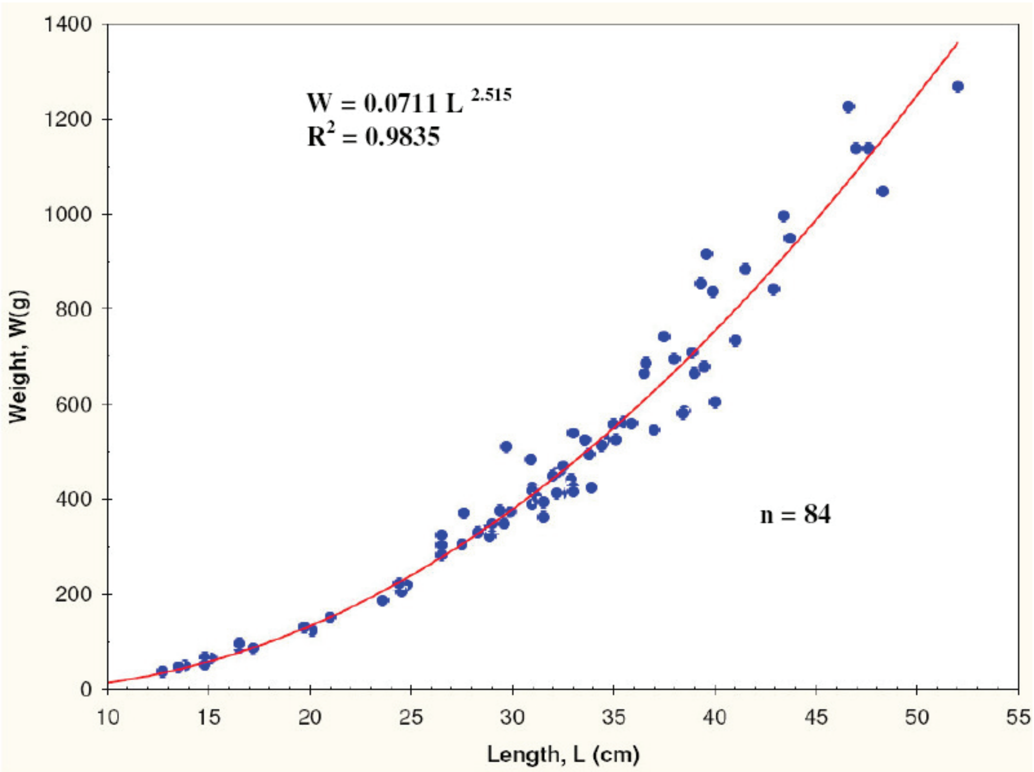


Fig. 20: Size-weight relationship of *Balistes capriscus* in western Gulf of Guinea

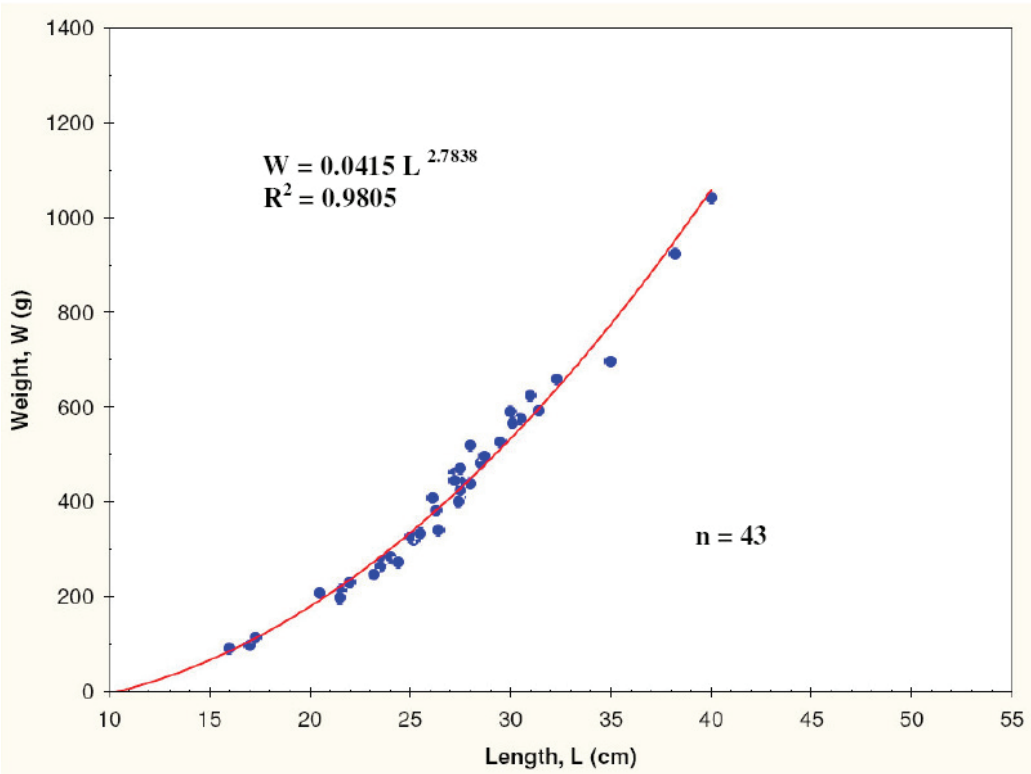


Fig. 21: Size-weight relationship of *Balistes punctatus* in western Gulf of Guinea

3.4.3 *Dorsal spine for ageing of triggerfish*

The image sections in Fig. 22 show at (a), a typical first dorsal spine image which was used to age *B. capriscus* (grey triggerfish) and (b), an example of spine for the ageing of *B. punctatus* (blue-spotted triggerfish). The spines normally have two out-growth or 'arms' which have annual rings embedded or imprinted in them. These arms extend from separate foci where they are broad in shape and taper towards the posterior tip. The annuli appear as alternate dark and light bands when viewed in two-dimension or as alternate crest and trough when viewed in three-dimension (Fig. 22).

Out of the 127 dorsal spines collected from triggerfish (*B. capriscus* and *B. punctatus*), 115 were suitable for ageing. The 115 triggerfish spines were comprised of 74 *B. capriscus* and 41

B. punctatus. For *B. capriscus*, out of 74 spine slides 66 were readable (89.2 %), the lengths of aged individuals ranged from 127 to 415 mm, ages 5-6 and 10-11 years were the dominant and least age classes respectively, 71.2 % of the fish were less than 7 years old and average percent error for ageing was 8.1 %. For *B. punctatus*, out of 41 spine slides 31 were readable (75.6 %), the lengths of aged individuals ranged from 160 to 280 mm, 4-5 year old fish were the dominant, 67.7 % of the fish were less than 7 years old and average percent error for ageing was 6.5 %.

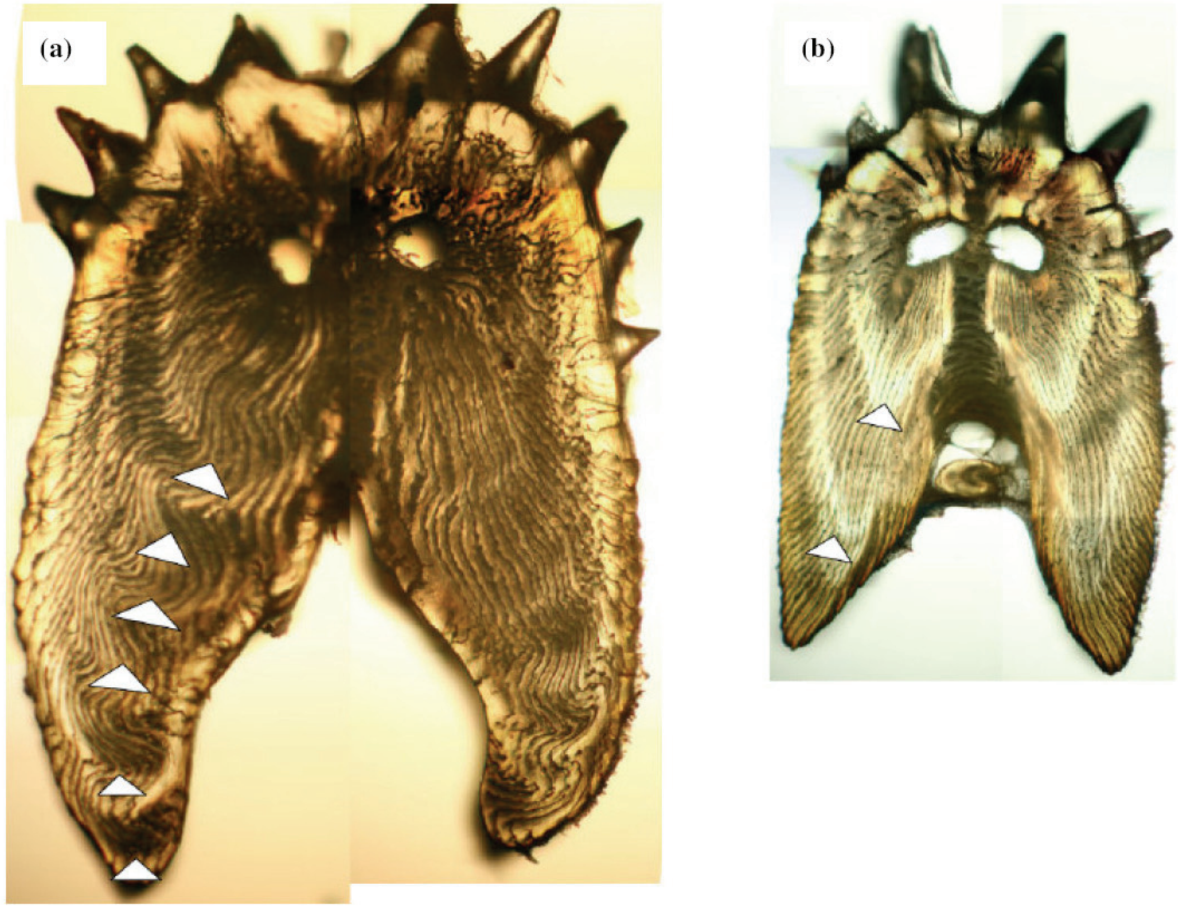


Fig. 22: Sections of triggerfish first dorsal spines collected in coastal waters of Ghana. (a) Spine section of *Balistes capriscus* (grey triggerfish) 6-yr-old female (348 mm TL), 15 May 2005. (b) Spine section of *Balistes punctatus* (blue-spotted triggerfish) 2-yr-old X-sex (160 mm TL), 12 May 2005. Where X-sex is unknown sex, probably females undergoing sex change at the time of capture

The use of otolith for ageing was tried but it was not successful. The tri-lobe or irregular shape of the otolith (see appendix, Fig. 31) makes it difficult to obtain all annuli rings after even careful cutting and polishing. Some rings were seen on the otolith slides that were prepared for this study, however the annuli either appear as multiples of rings or sometimes the rings were quite clear but without a nucleus irrespective of the cutting plane. Therefore, the otolith ring counting was ignored in this study.

3.4.4 *Growth parameters of* Balistes capriscus

Fig. 23 shows the relationship between total length (mm) and age (years) of *Balistes capriscus* in the western Gulf of Guinea. The plots represent von Bertalanffy growth relation obtained for the observed data. The growth equation was fitted to the observed age at length data obtaining the following growth parameters: theoretical length (L_∞), 450.81±14.07 mm (SE) and growth coefficient (K), 0.21 year^{-1} using FiSAT programme. The growth parameters obtained from weighted mean back-calculation (derived data) (see Table 3 below) were L_∞ = 545.14±74.77 mm and K = 0.18 (1/year). Similarly, growth parameters obtained from all back-calculation including end-points (derived data) of *Balistes capriscus* were L_∞ = 485.88±19.17 mm and K = 0.22 (1/year).

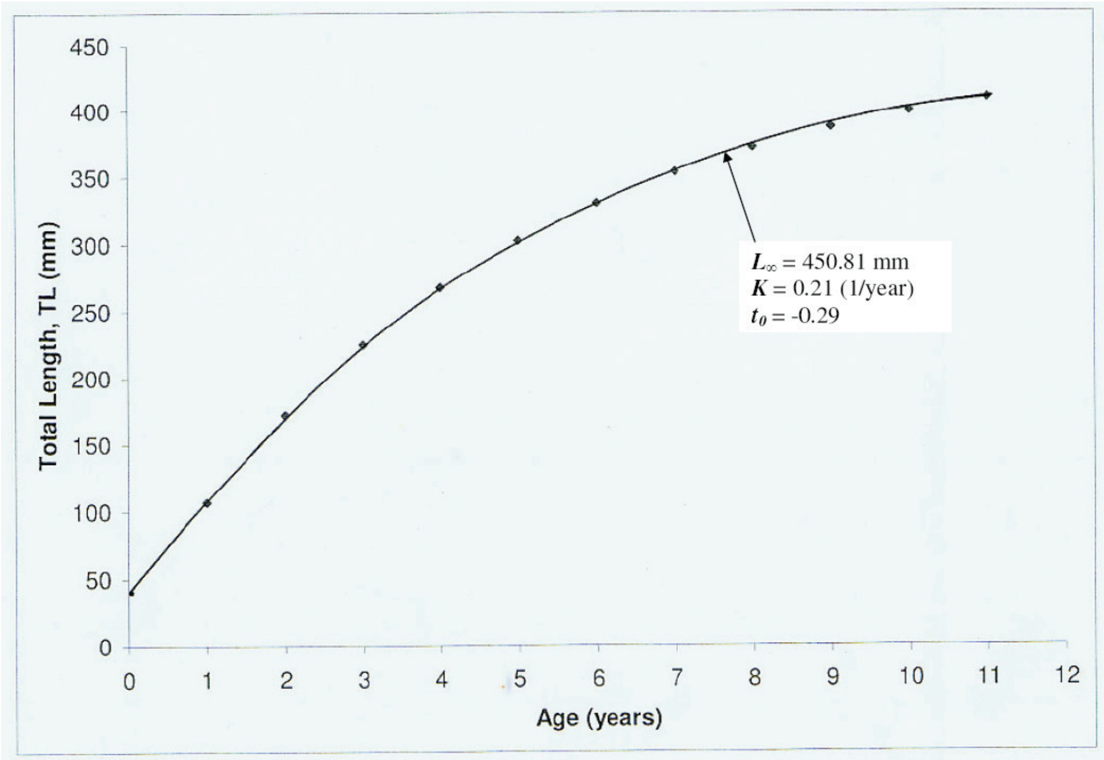


Fig. 23: von Bertalanffy growth curve of *Balistes capriscus* (grey triggerfish). Growth parameters from observed data

3.4.5 *Relationship between total length and spine radius of* Balistes capriscus

Fig. 24 show the relationship of total length, *TL* (mm) of *Balistes capriscus* and spine radius, *SR* (mm).

The total length-spine radius relationship showed high regression coefficient, $R^2 = 0.9777$ for *B. capriscus* (Fig. 24). The power function of the total length-spine radius relationship of *B. capriscus* was as follows:

$$TL = 173.42\ [SR]^{1.2696}$$

where *TL* (mm) is the total length and *SR* (mm) is the spine radius.

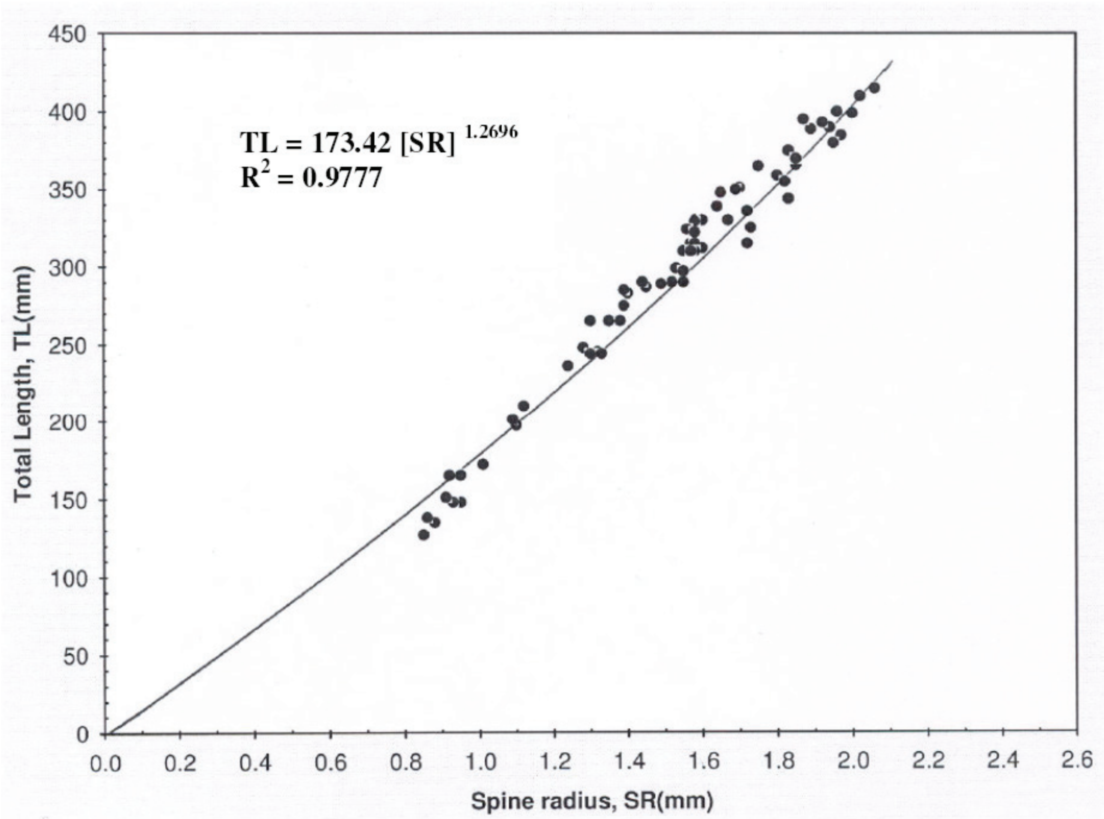


Fig. 24: Total length and spine radius relationship of *Balistes capriscus* in the western Gulf of Guinea

Table 3 show the back-calculated total lengths (mm) at age using the power function for grey triggerfish in the western Gulf of Guinea. The back-calculation shows a calculated mean length of fish at annulus, total spines considered for a particular annulus counting based on the number of specimens in various age groups and estimated growth increment from successive annulus in *Balistes capriscus*. From Table 3, the variation in fish length at annuli 1, 2, 5, 6 and 7 are much higher whereas that of annuli 9 and 10 are lower. Back-calculated lengths in this study for grey triggerfish ranged from 140.6 mm for age 1 fish to 474.6 mm *TL* for fish 11 years old. The annual increments in fish length were much wider from 140.6 mm to 47.0 mm at the initial annuli stages and tend to be smaller from 33.4 mm, 31.9 mm to 44.1 mm towards latter formed annuli and much smaller at older age from 14.0 mm to 12.2 mm at annuli 10 and 11 increments for grey triggerfish (Table 3).

Table 3: Back-calculated total lengths (mm) at age of grey triggerfish from the western Gulf of Guinea

Age	N	Annulus										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2	9	102.3	156.0									
3	3	160.3	195.7	227.9								
4	10	130.6	171.2	218.6	253.8							
5	13	120.4	164.7	223.2	258.6	285.3						
6	13	118.3	171.2	244.3	253.8	282.8	310.0					
7	3	171.2	207.1	242.0	270.7	292.6	322.5	360.6				
8	3	166.8	209.4	249.1	278.0	305.0	352.9	378.7	412.8			
9	6	145.3	204.8	244.3	287.7	320.0	370.9	399.6	434.1	447.5		
10	4	145.3	198.0	239.6	275.5	307.5	345.2	386.5	412.8	442.1	458.3	
11	2	145.3	198.0	246.7	287.7	325.0	378.7	407.5	423.4	455.6	466.4	474.6
Total	66	66	66	57	54	44	31	18	15	12	6	2
Weighted mean±1SD		140.6 ±22.5	187.6 ±19.7	237.3 ±11.1	270.7 ±14.0	302.6 ±16.5	346.7 ±26.8	386.6 ±18.3	420.8 ±10.2	448.4 ±6.8	462.4 ±5.7	474.6 -
Annual increment		140.6	47.0	49.7	33.4	31.9	44.1	39.9	34.2	27.6	14.0	12.2

3.4.6 *Growth parameters of* Balistes punctatus

Fig. 25 shows the relationship between total length (mm) and age (years) of *Balistes punctatus* from the western Gulf of Guinea. The plots represent von Bertalanffy growth relation obtained from observed data. The growth equation was fitted to the observed age at length data obtaining the following growth parameters: theoretical length (L_∞), 282.26±3.79 mm (SE) and growth coefficient (K), 0.38 year^{-1} using FiSAT programme. The growth parameters obtained from weighted mean back-calculation (derived data) (see Table 4 below) were L_∞ = 295.27±15.22 mm and K = 0.40 (1/year). The growth parameters obtained from all back-calculation including end-points (derived data) of *Balistes punctatus* were L_∞ = 275.76±3.38 mm and K = 0.48 (1/year).

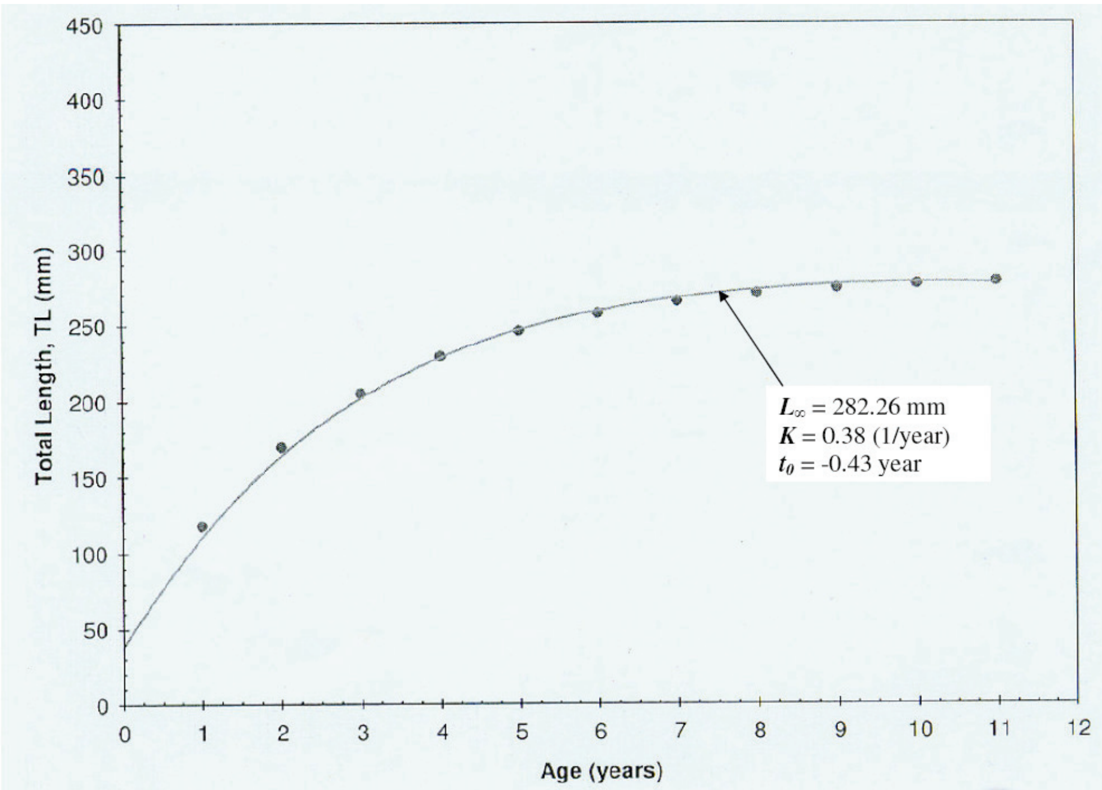


Fig. 25: von Bertalanffy growth curve of *Balistes punctatus* (blue-spotted triggerfish). Growth parameters derived from reading data

3.4.7 *Relationship between total length and spine radius of* Balistes punctatus

In Fig. 26, the relationship between total length, *TL* (mm) and spine radius, *SR* (mm) of *Balistes punctatus* are shown.

The plots of total length-spine radius relationship showed high regression coefficient, R^2 = 0.9533 for *B. punctatus* (Fig. 26). The power function of the total length-spine radius relationship of *B. punctatus* was as follows:

$$TL = 165.30\ [SR]^{0.6358}$$

where *TL* (mm) is the total length and *SR* (mm) is the spine radius.

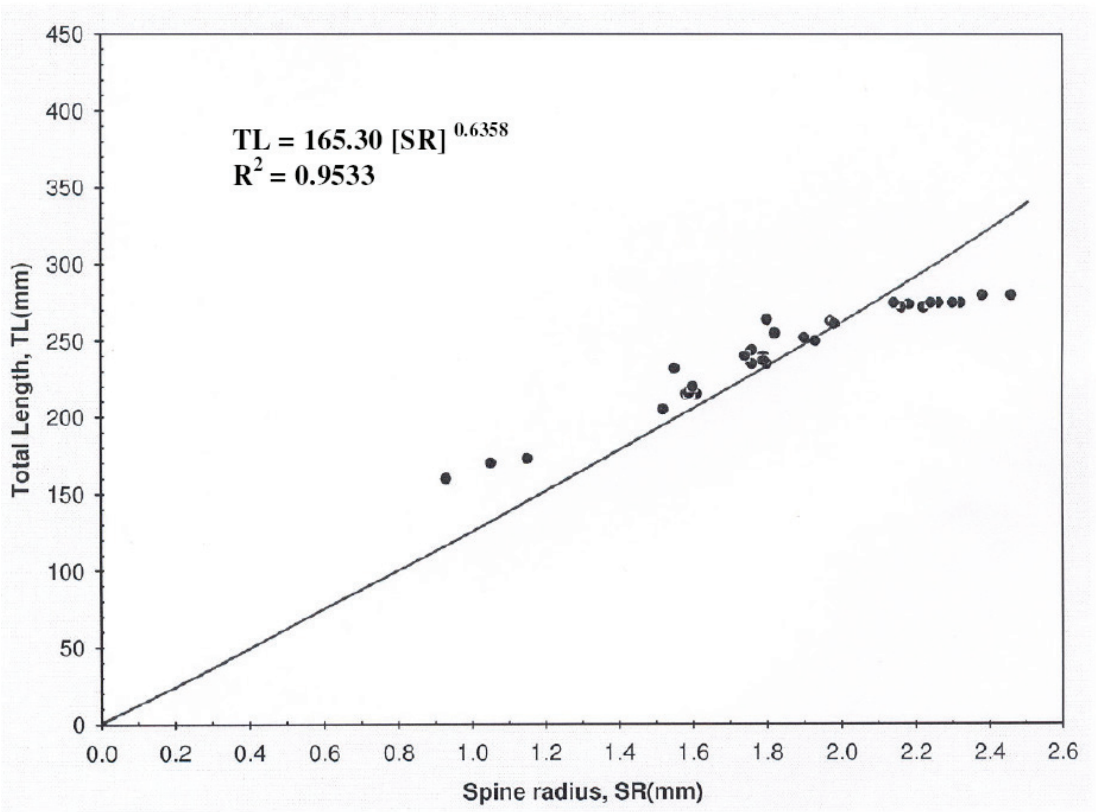


Fig. 26: Total length and spine radius relationship of *Balistes punctatus* in the western Gulf of Guinea

Table 4 show the back-calculated total lengths (mm) at age using the power function for blue-spotted triggerfish from the western Gulf of Guinea. The back-calculation shows a calculated mean length of fish at annulus, total spines considered for a particular annulus counting based on the number of specimens in various age groups and estimated growth increment from successive annulus in *Balistes punctatus*. The blue-spotted triggerfish showed high fish length variation at annuli 1, 2 and 3 whereas that of 7, 9 and 10 are lower (Table 4). The back-calculated lengths for blue-spotted triggerfish range from 131.4 mm for age 1 fish to 310.1 mm *TL* for fish 11 years old. The annual increments in fish length were very much wider from 131.4 mm to 40.7 mm (that is, annulus 1 to annulus 2 increments) again annual increment decreases towards latter formed annuli from 21.0 mm, 17.6 mm to 12.6 mm (that is, annulus 4, 5 and 6 increments) and remained constant at older age, 9.0 mm each for annuli 10 and 11 increments in blue-spotted triggerfish (Table 4).

The back-calculated lengths for the two species of triggerfish in the western Gulf of Guinea at age 1 were 140.6 mm for *B. capriscus* and 131.4 mm for *B. punctatus* which were much comparable than that at age 11 (474.6 mm for *B. capriscus* and 310.1 mm for *B. punctatus*). However, the variations in length of blue-spotted triggerfish lower annuli were much smaller than that of the grey triggerfish. The extent of annual increment at age 11 (12.2 mm for *B. capriscus* and 9.0 mm for *B. punctatus*) appears to be similar in both species of triggerfish (Tables 3 and 4).

Table 4: Back-calculated total lengths (mm) at age of blue-spotted triggerfish from the western Gulf of Guinea

Age	**N**	**Annulus**										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2	3	115.6	175.6									
3	4	124.5	170.5	211.2								
4	3	125.7	160.0	192.4	219.3							
5	6	123.2	155.7	191.5	219.3	237.6						
6	5	129.4	164.2	193.4	218.4	235.9	246.9					
8	5	141.1	179.7	205.7	225.5	244.4	257.7	268.9	278.3			
10	3	144.6	182.7	208.4	228.1	244.4	256.0	268.9	284.6	293.7	302.7	
11	2	146.8	188.6	215.7	230.8	243.6	254.4	266.5	280.7	290.7	299.7	310.1
Total	31	31	31	28	24	21	15	10	10	5	5	2
Weighted mean±1SD		131.4 ±11.4	172.1 ±11.6	202.6 ±10.0	223.6 ±5.3	241.2 ±4.1	253.8 ±4.8	268.1 ±1.4	281.2 ±3.2	292.2 ±2.1	301.2 ±2.1	310.1 -
Annual increment		131.4	40.7	30.5	21.0	17.6	12.6	14.3	13.1	11.0	9.0	9.0

3.4.8 *Comparison of growth performance of triggerfish*

Table 5 shows the reported growth parameters of triggerfish and their calculated growth performance (ϕ') during dominance and collapse eras in West African waters. The growth of *B. capriscus* and *B. punctatus* in the western Gulf of Guinea had not changed significantly for the last two-and-half decades (Table 5). The growth performance obtained in this study is 2.63 for *B. capriscus* which is comparable to that obtained in the 1980s on the same fish species in waters of Senegal, Côte d'Ivoire and Ghana. The growth performance obtained for *B. punctatus* in this study is 2.48 (given L_∞ = 28.2±0.4 cm and K = 0.38 from observed data).

The mean of L_∞ of *Balistes capriscus* for both sexes in Senegal, Côte d'Ivoire and Ghana is 40.83±0.09 cm (SE) for 95 % confidence interval; whereas the L_∞ of *B. capriscus* in this study is 45.1±1.4 cm (SE). Where SE denotes standard error.

Table 5: Parameters of the von Bertalanffy's growth function of *Balistes capriscus* obtained from literature and estimates of growth performance, ϕ'. L_∞ and K for this study were obtained from observed data. All ϕ' were calculated in this study. Dominance phase of triggerfish occurred in 1970s and early 1980s; and collapse phase occurred in the late 1980s

Area	$\mathbf{L_\infty}$	**K**	**ϕ'**	**Remarks**	**Source**
Senegal	37.5	0.45	2.80	Male	Caverivière (1982)
Senegal	38.0	0.35	2.70	Female	Caverivière (1982)
Senegal	40.7	0.31	2.71	Both sexes	Caverivière (1982)
Côte d'Ivoire	41.0	0.11	2.27	Both sexes	Caverivière (1982)
Ghana	40.8	0.43	2.85	Both sexes	Ofori-Danson(1989)
Ghana	45.1±1.4	0.21±0.02	2.63	Both sexes	This study

3.5 Diet availability of triggerfish in coastal waters of Ghana

The gut analysis of *Balistes capriscus* and *Balistes punctatus* were studied as presented in Tables 6–9. Percent frequency of occurrence and gravimetric composition of both species of triggerfish are indicated below (Tables 6-9). The numerical method did not worked out well as most of the food items in the gut were in pieces. However, there were few whole organisms which were counted such as *Sepia* juveniles, copepods, amphipods, nematodes, etc.

In Tables 6 and 7, 74 gut specimens of *B. capriscus* comprised of 65 guts with food contents and 9 empty guts were analysed. Food items were grouped into four categories, namely: zooplankton, benthic macroinvertebrates, vertebrates and miscellaneous food items.

In Table 6, the percent frequency of occurrence indicates that Mysidae and Anthomedusa occurred in size class 12.0-21.9 cm whereas Amphipoda (hyperiids) dominated in size class 22.0-31.9 cm. Zooplankton were least represented in size class 32.0-41.9 cm and no zooplankton recorded in the higher size class (42.0-52.0 cm) of *B. capriscus*. Decapoda such as crabs, lobsters and shrimps; and Sepiidae such as *Sepia* sp. dominated in all the size classes in benthic macroinvertebrates group. Vertebrates which were mainly fish bones, scales and fins were dominant in size class 32.0-41.9 cm. Miscellaneous group of food items was dominated by mollusc shells which were mostly in fragments (Table 6).

In Table 7, the percent gravimetric composition indicates low values of zooplankton food items; and benthic macroinvertebrates were dominated by lobsters in size classes 22.0-31.9 cm and 42.0-52.0 cm. Sepiidae dominated in size class 42.0-52.0 cm whereas Nematoda, Polychaeta and Volutacea (*Cybium*) were least represented in the food items. Vertebrate group was dominated by fragments of fish which were much represented in 12.0-21.9 cm size class. Again, miscellaneous group comprised of mollusc shells and marine debris where fragments of mollusc shells dominated in almost all the size classes (Table 7).

Table 6: Percent Frequency of Occurrence of *Balistes capriscus*. Gut specimens collected during Fridtjof Nansen survey 2005 in the western Gulf of Guinea

Food items	Size class (TL/cm)			
	12.0 – 21.9	22.0 – 31.9	32.0 – 41.9	42.0 – 52.0
(A) Zooplankton				
Amphipoda: Hyperiids	-	9.1	1.4	-
Copepoda	-	1.8	1.4	-
Eupausiidae	-	1.8	-	-
Mysidae	3.0	-	-	-
Anthomedusa	3.0	-	-	-
Jellyfish	-	-	1.4	-
Fish larvae (Batoid)	-	-	1.4	-
(B) Benthic macroinvertebrates				
Bivalvia	3.0	5.5	4.1	-
Decapoda:				
Brachyura (Crabs)	12.2	1.8	6.8	4.0
Nephropidae (Crayfish/Lobsters)	9.1	16.4	12.3	8.0
Penaeidae (shrimps)	6.1	3.6	5.5	12.0
Sepiida:				
Sepia/Flesh of Sepia	-	3.6	5.5	24.0
Nematoda	3.0	7.3	8.2	8.0
Polychaeta	3.0	1.8	-	-
Volutacea: (Cybium)	-	-	1.4	-
Shell of siphonidae	3.0	-	-	-
(C) Vertebrates				
Fish bones/scales/fins	3.0	3.6	9.6	4.0
(D) Miscellaneous				
Mollusc shells	18.2	10.9	11.0	16.0
Marine debris	3.0	-	4.1	-
Digested materials	30.4	32.7	26.0	24.0

See Appendix 7 (Table 14) for details: No. of fish, No. of empty and non-empty guts analysed.

Table 7: Percent Gravimetric composition of *Balistes capriscus.* Gut specimens collected during Fridtjof Nansen survey 2005 in the western Gulf of Guinea

Food items	**Size class (TL/cm)**			
	12.0 – 21.9	**22.0 – 31.9**	**32.0 – 41.9**	**42.0 – 52.0**
(A) Zooplankton				
Amphipoda: Hyperiids	-	-	-	-
Copepoda	-	-	-	-
Eupausiidae	-	-	-	-
Mysidae	0.1	-	-	-
Anthomedusa	-	-	-	-
Jellyfish	-	-	0.1	-
Fish larvae (Batoid)	-	-	-	-
(B) Benthic macroinvertebrates				
Bivalvia	-	0.5	0.4	-
Decapoda:				
Brachyura (Crabs)	7.3	1.5	9.3	1.4
Nephropidae (Crayfish/Lobsters)	6.2	32.0	11.6	17.1
Penaeidae (shrimps)	-	0.5	4.7	2.2
Sepiida:				
Sepia/Flesh of Sepia	-	1.7	9.8	58.0
Nematoda	0.2	0.2	-	-
Polychaeta	1.0	0.1	-	-
Volutacea: (Cybium)	-	-	0.2	-
Shell of siphonidae	-	-	-	-
(C) Vertebrates				
Fish bones/scales/fins	7.7	1.5	2.3	1.6
(D) Miscellaneous				
Mollusc shells	9.4	4.4	18.2	19.7
Marine debris	0.9	-	4.2	-
Digested materials	67.1	57.5	39.2	-

See Appendix 7 (Table 15) for details: No. of fish, No. of empty and non-empty guts analysed.

In Tables 8 and 9, 41 gut specimens of *B. punctatus* comprised of 41 guts with food contents and no empty guts occurred. Again, food items were grouped into four categories, namely: zooplankton, benthic macroinvertebrates, vertebrates and miscellaneous food items.

The percent frequency of occurrence in Table 8 indicates that zooplankton group was dominated by Amphipoda (hyperiids) in 12.0-21.9 cm, and Mysidae in 32.0-41.9 cm size classes whereas gastropod larvae and bivalve larvae were least represented in 22.0-31.9 cm. Benthic macroinvertebrates dominated by Bivalvia and Nephropidae (crayfish/lobsters) in 12.0-21.9 cm; and Brachyura (crabs), Penaeidae (shrimps) and fragments of Echinodea in 22.0-31.9 cm size class. Decapoda such as lobsters and shrimps, and Echinodea dominated in 32.0-41.9 cm size class (Table 8).

Vertebrate (fish fragments) were high in percentage in 32.0-41.9 cm. Miscellaneous which consisted of mollusc shells, marine debris, sand grains and unidentified food items were recorded in almost all the size groups of *B. punctatus*.

In Table 9, the percent gravimetric composition indicates low values of zooplankton food items which consists of Amphipoda (hyperiids), Mysiidae, Cumacea and lamellibranch larvae. Gastropod larvae and bivalve larvae did occurred but their percent gravimetric composition was negligible. Benthic macroinvertebrates group was dominated by Bivalvia and Penaeidae (shrimps) in size class 12.0-21.9 cm; Brachyuran (crabs), fragments of Echinodea and Penaeidae dominated in 22.0-31.9cm; and Bivalvia, Nephropidae (crayfish/lobsters) and fragments of Echinodea dominated in 32.0-41.9 cm. Vertebrates (fish fragments) were represented in higher size class, 32.0-41.9 cm. Miscellaneous which consists of mollusc shells, marine debris, sand grains and unidentified were least represented in almost all the size classes of *B. punctatus*.

Table 8: Percent Frequency of Occurrence of *Balistes punctatus.* Gut specimens collected during Fridtjof Nansen survey 2005 in the western Gulf of Guinea

Food items	**Size class (TL/cm)**		
	12.0 – 21.9	**22.0 – 31.9**	**32.0 – 41.9**
(A) Zooplankton			
Amphipoda: Hyperiids	4.5	1.8	-
Mysidae	-	1.8	5.3
Cumacea	4.5	0.9	-
Lamellibranch larvae	-	1.8	5.3
Gastropod larvae	-	0.9	-
Bivalve larvae	-	0.9	-
(B) Benthic macroinvertebrates			
Bivalvia	13.6	3.6	10.5
Decapoda:			
Brachyura (Crabs)	9.1	10.7	5.3
Nephropidae (Crayfish/Lobsters)	13.6	6.3	10.5
Penaeidae (shrimps)	9.1	19.7	10.5
Sepiida:			
Sepia/Flesh of Sepia	-	3.6	-
Echinodea (pieces)	4.5	11.6	10.5
(C) Vertebrates			
Fish bones/scales/fins	-	1.8	15.8
(D) Miscellaneous			
Mollusc shells	9.1	4.5	5.3
Marine debris	4.5	7.1	-
Sand grains/stones	-	0.9	5.3
Unidentified	9.1	-	-
Digested materials	18.2	22.3	15.8

See Appendix 7 (Table 16) for details: No. of fish, No. of empty and non-empty guts analysed.

Table 9: Percent Gravimetric composition of *Balistes punctatus*. Gut specimens collected during Fridtjof Nansen survey 2005 in the western Gulf of Guinea

Food items	**Size class (TL/cm)**		
	12.0 – 21.9	**22.0 – 31.9**	**32.0 – 41.9**
(A) Zooplankton			
Amphipoda: Hyperiids	0.5	-	-
Mysidae	-	0.1	0.3
Cumacea	0.3	0.1	-
Lamellibranch larvae	-	-	0.1
Gastropod larvae	-	-	-
Bivalve larvae	-	-	-
(B) Benthic macroinvertebrates			
Bivalvia	7.9	0.8	10.4
Decapoda:			
Brachyura (Crabs)	0.5	6.2	1.4
Nephropidae (Crayfish/Lobsters)	5.5	1.3	15.2
Penaeidae (shrimps)	37.6	38.2	0.4
Sepiida:			
Sepia/Flesh of Sepia	-	3.9	-
Echinodea (pieces)	4.6	16.0	9.9
(C) Vertebrates			
Fish bones/scales/fins	-	-	25.2
(D) Miscellaneous			
Mollusc shells	-	1.7	-
Marine debris	2.6	7.4	-
Sand grains/stones	-	-	0.4
Unidentified	0.5	-	-
Digested materials	39.9	24.2	36.6

See Appendix 7 (Table 17) for details: No. of fish, No. of empty and non-empty guts analysed.

The analysis of capture of main diet of triggerfish in coastal waters of Ghana is to assess whether with the disappearance of triggerfish the production of the main diet has also been affected over the years. It is known that triggerfish diet is mainly of marine crustaceans and molluscs (Ofori-Danson 1981, Aggrey-Fynn, unpublished). The crustaceans and molluscs consist of decapods, cuttlefish, marine crabs and lobsters in coastal waters of Ghana. Over the last two decades the capture production of these crustaceans and molluscs in Ghana had increased with the collapse of triggerfish. This study assess the changes in the capture of natantian decapods, cuttlefish, marine crabs and tropical marine lobsters over the period 1978-2003 which are presumed prey of triggerfish in relation to triggerfish capture (1972-2003) in Ghanaian coastal waters.

Time series plots in Fig. 27 shows yearly fluctuations in the capture of the main diet of triggerfish over the period 1978-2003. The figure shows increase in the capture of cuttlefish from 1980-1984. Capture of cuttlefish declined slightly from 1985-86. Cuttlefish capture showed a general increase after 1986 reaching a peak in 1991 and decreased again in 1992. The cuttlefish catch picked up in 1993 increasing continuously until 1999 and decreased again in 2000. Since 2001 up to 2003 cuttlefish capture had increased to a record high of 5 500 tons in 2003. In the case of natantian decapods the capture from 1978-1986 was relatively low as compared to that of cuttlefish. In 1987, capture of natantian decapods increased to almost the same level as that of cuttlefish. Natantian decapods capture declined slightly in 1988, but increased again from 1989 to a record high of 2 637 tons in 1990. The natantian decapods capture decreased in 1991, increased in 1992, decreased again in 1993 and generally increased from 1994-95. From 1996 up to 2003, there has been a generally constant capture of natantian decapods in coastal waters of Ghana. In the case of triggerfish, the catch increased from 1972-1977, reaching a peak of 12 563 tons in 1979. Generally, triggerfish catch declined from 1980-85. The triggerfish catch reached a record high of 17 559 tons in 1986/87 and then decreased tremendously in 1988 to 2 862 tons. The decline of triggerfish catch continued from 1989 up to 2003. The capture increase is much obvious in the cuttlefish since after the collapse of triggerfish in 1988 to date. Cuttlefish and natantian decapods increased together after the collapse of triggerfish fishery until 1989/90 when cuttlefish out-numbered decapods. Natantian decapods capture has stayed constant for sometime whilst that of cuttlefish has been on the ascendancy since the disappearance of triggerfish.

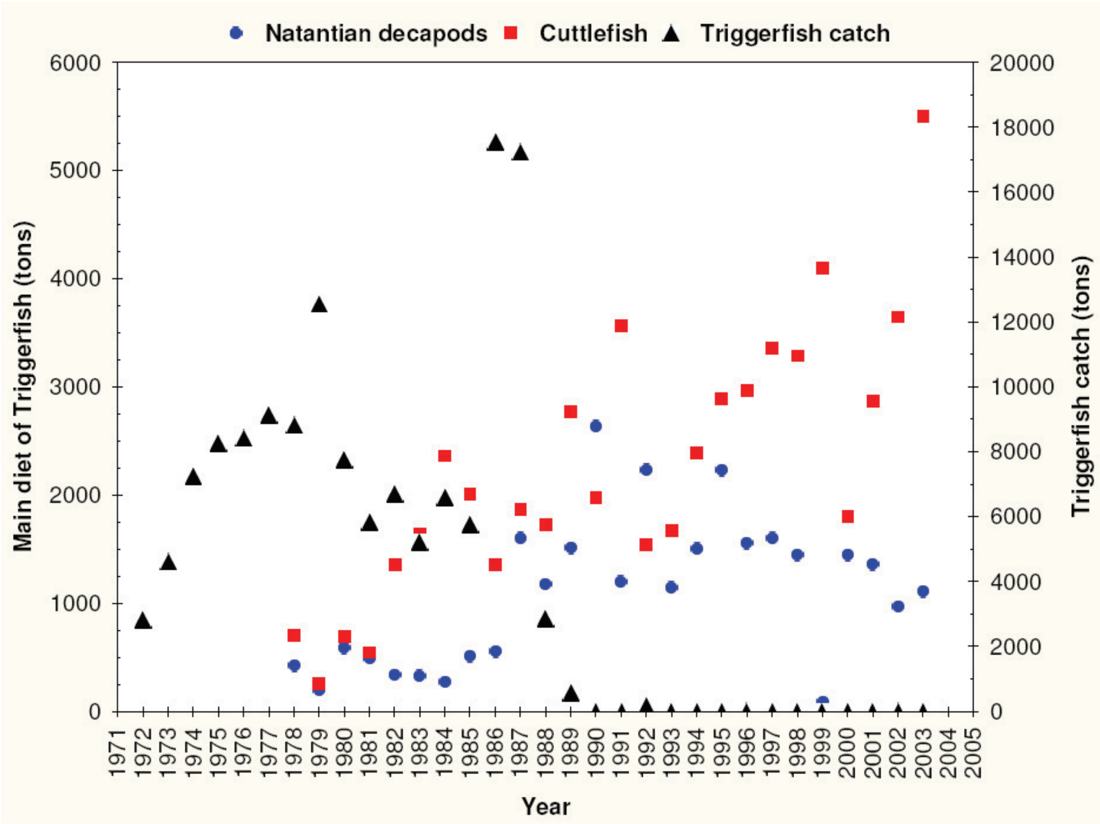


Fig. 27: Time series plots of capture of main diet of triggerfish in coastal waters of Ghana from 1978-2003 for natantian decapods and cuttlefish. Yearly plots of natantian decapods represented as blue round plots and cuttlefish represented as red square plots (Data source: FAO 1983, 1986, 1996 and 2006). Triggerfish catch: 1972-2003 (Data source: Fishbase). The triggerfish catch is represented as black triangle plots

Time series plots in Fig. 28 shows yearly fluctuations in the capture of the main diet of triggerfish over the period 1979-2003 for marine crabs, and 1981-2003 for tropical spiny lobsters. The marine crabs capture has been low from 1979-1986. There was increase in the capture of marine crabs from 1987-88, and then capture declined in 1989 and increased again 1990. The 1991 and 1992 capture of marine crabs was low but the capture increased in 1993-97 reaching a record high of 576 tons in 1997. Marine crabs capture declined in 1998-2000 and increased from 2001-2003. In the case of tropical spiny lobsters, the capture was almost at the same low level from 1981-1985, and increased tremendously in 1986-87 reaching a record high of 754 tons in 1987. The tropical spiny lobsters capture declined from 1988-91, and increased from 1992-94. In 1995-96 lobsters capture declined, and generally increased from 1997-2001. Tropical spiny lobsters capture had declined in 2002 and 2003 to a record low of 28 tons in 2003. In the case of triggerfish, the catch increased from 1972-1977, reaching a peak of 12 563 tons in 1979. Generally, triggerfish catch declined from 1980-85. The triggerfish catch reached a record high of 17 559 tons in 1986/87 and then decreased tremendously in 1988 to 2 862 tons. The decline of triggerfish catch continued from 1989 up to 2003.

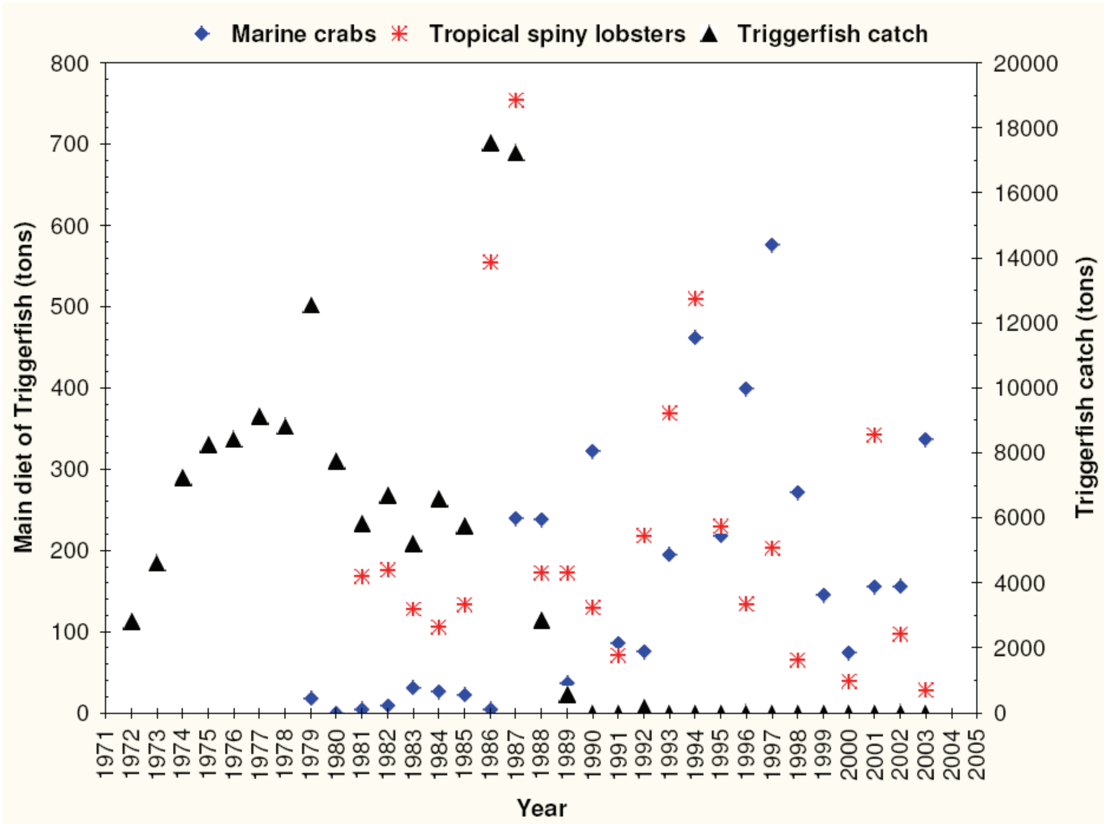


Fig. 28: Time series plots of capture of main diet of triggerfish in coastal waters of Ghana from 1979-2003 for marine crab represented as blue diamond plots, and 1981-2003 for tropical spiny lobsters represented as red asterisk plots (Data source: FAO 1983, 1986, 1996 and 2006). Triggerfish catch: 1972-2003 represented as black triangle plots (Data source: Fishbase)

3.6 Mortality and rate of exploitation

Using Rikhter and Efanov's method,

$$M = [1.52/(t_{mass})^{0.72}] - 0.16$$

Natural mortality (M) was derived as follows when t_{mass} is taken as 4 years:

Then, M = 0.4000

where t_{mass} is the age (in years) at massive maturation. In this study, t_{mass} is deduced from Ofori-Danson (1990) as *Balistes capriscus* of size range 145-200 mm *FL* which corresponds to 230-250 mm *TL* of *Balistes capriscus* in this study. This size of fish was estimated to be 4 – 5 years approximately (see Fig. 23).

Alternatively, natural mortality rate (M) was derived from the empirical formula developed by Pauly (1980) as follows:

$$\log_{10} M = -0.0066 - 0.279\log_{10} L_\infty + 0.6543\log_{10} K + 0.4634\log_{10} T$$

where M is natural mortality, L_∞ (TL) is expressed in cm, K is the rate of growth of fish and T is the mean annual environmental temperature (here taken as 22.0 °C for cooler periods and 25.0 °C for normal periods in Ghanaian coastal waters).

For T = 22.0 °C,

M was estimated to be 0.5178 (for L_∞ = 48.588 cm and K = 0.22 year $^{-1}$ obtained from back-calculated data including end-points). The previous M estimates in Koranteng (1998) using Ofori-Danson (1981 and 1989) growth parameters of *Balistes capriscus* was based on cooler temperature (T = 20 °C) in coastal waters of Ghana. Hence, a threshold of cooler temperature (T = 22 °C) in Ghanaian waters was also used in this study for comparison purposes in periods of abundance and collapse of triggerfish resource.

The instantaneous rate of total mortality (Z) was estimated using length-converted catch curve model (FiSAT programme) where:

Ln (N/ dt) is plotted against relative age (years) from the relation:

$$\text{Ln } N/dt = a + b\,t$$

where *N* denotes the number of fish, and *t* denotes age.

Z being estimated from the slope *b* of the descending right arm of the plot (see Fig. 29), whereas plots belonging to the ascending left arm of the curve was not included since they represent incomplete recruited *Balistes capriscus*.

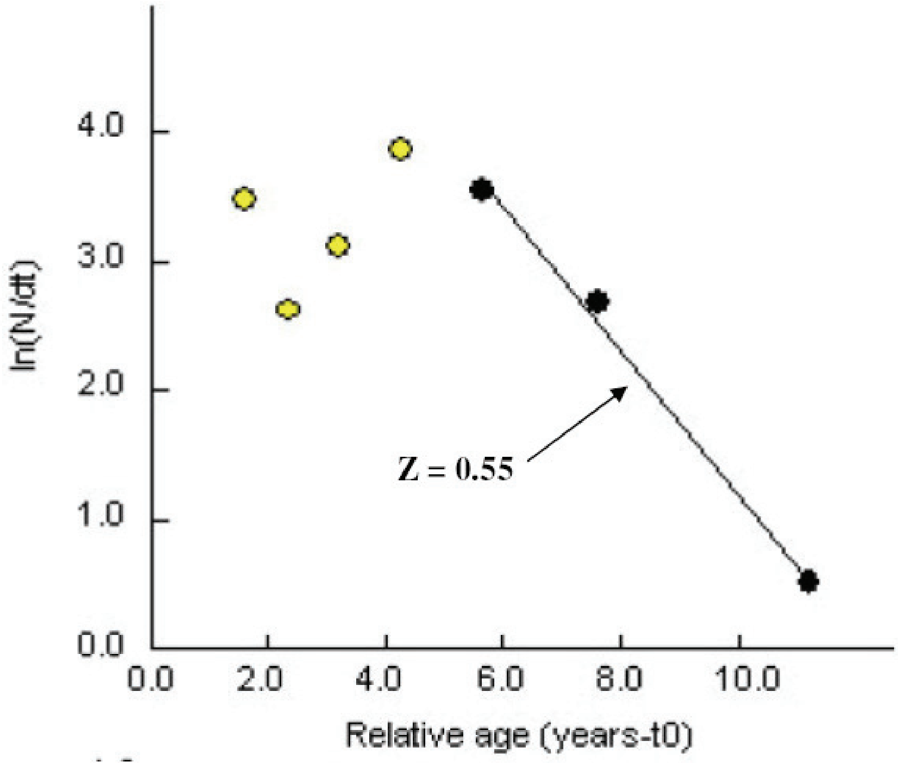


Fig. 29: Length-converted catch curve of *Balistes capriscus* for estimation of Z. Yellow points represent ascending left arm, and black points represent descending right arm. Size-distribution data were obtained from Fridtjof Nansen survey 2005 (sample size 84) in Fig. 18. Growth parameters were obtained from all back-calculation including end-points (derived data) of *B. capriscus*

Following estimation of *Z* and *M*, the fishing mortality (*F*) rate was calculated from $F = Z - M$, and the exploitation ratio, $E = F/Z$ was then computed (Tables 10 and 11). In Table 10, *E* was computed from *Z* derived from Length-converted catch curve for various growth parameters estimated from observed data, all back-calculation including end-points and weighted mean back-calculation (derived data); and *M* obtained from Rikhter and Efanov's method. It was observed that *Balistes capriscus* data from all back-calculations including end-points and weighted mean back-calculation (derived data) gave better growth parameters which show that the fishery resource is under-exploited and lightly exploited respectively in western Gulf of Guinea. Again, it was observed that *M* in many cases was higher than or closer to *Z*. This could be true because the mortality of triggerfish in recent times is mainly due to natural causes rather than fishing activities since the resource had disappeared for nearly two decades in coastal waters of Ghana.

Table 10: Comparison of total mortality (*Z*), fishing mortality (*F*) and exploitation ratio (*E*) of *Balistes capriscus* for growth parameters obtained from: a) observed data, b) all back-calculation including end-points (derived data) and c) weighted mean back-calculation (derived data). Natural mortality (*M*) was obtained from Rikhter and Efanov's method, where $M = 0.4000$

L_∞	K	Z	F	E
a) 45.081	0.21	0.31	-	-
b) 48.588	0.22	0.55	0.150	0.2727
c) 54.514	0.18	0.43	0.030	0.0698

In Table 11, *E* was computed from *Z* derived from Length-converted catch curve for various growth parameters obtained from observed data, all back-calculation including end-points (derived data) and weighted mean back-calculation (derived data); and *M* calculated from Pauly's *M* equation. It was observed that *Balistes capriscus* data from (b) all back-calculation including end-points gave better growth parameter which shows that the fishery resource is under-exploited in western Gulf of Guinea. Again, *M* in many instances were higher than or quite close to *Z* for the fact that mortality of triggerfish in recent years is mainly dependent on natural causes rather than fishing activities due to the collapse of the triggerfish resource.

Table 11: Comparison of total mortality (*Z*), fishing mortality (*F*) and exploitation ratio (*E*) of *Balistes capriscus* for growth parameters obtained from: a) observed data, b) all back-calculation including end-points (derived data) and c) weighted mean back-calculation (derived data). Natural mortality (*M*) was calculated from Pauly's *M* equation for *T* = 22 °C

L_∞	K	M	Z	F	E
a) 45.081	0.21	0.51287	0.31	-	-
b) 48.588	0.22	0.51778	0.55	0.032	0.0582
c) 54.514	0.18	0.43972	0.43	-	-

In Table 12, *M* values were derived from Pauly's *M* equation using mean environmental temperature from 1974-2004 in coastal waters of Ghana. The usual way of calculating Pauly's *M* was done to verify the observations in Tables 10 and 11 that *M* is either very close to and/or higher than *Z*. There were indications in Tables 11 and 12 that *M* is quite close to *Z* for growth parameters obtained from derived data. But this possibility could only occur in the case of a collapsed fishery resource.

Table 12: Comparison of total mortality (*Z*), fishing mortality (*F*) and exploitation ratio (*E*) of *Balistes capriscus* for growth parameters obtained from: a) observed data, b) all back-calculation including end-points (derived data) and c) weighted mean back-calculation (derived data). Natural mortality (*M*) was calculated from Pauly's *M* equation for *T* = 26.5 °C

L_∞	K	M	Z	F	E
a) 45.081	0.21	0.55902	0.31	-	-
b) 48.588	0.22	0.56437	0.55	-	-
c) 54.514	0.18	0.47929	0.43	-	-

3.6.1 *F, M and Z in collapsed fisheries scenario*

Considering fishing (F), natural (M) and total (Z) mortalities of a fisheries resource which is collapsed, for instance, triggerfish fisheries resource in Ghana.

Z is supposed to be the sum of *M* and *F*, so at least for negligible *F* (since the fisheries had collapsed), *Z* should have been equal to *M*. But in nature, $1 + 1 \neq 2$ meaning that natural causes of mortality may be varying from time to time to either increase or decrease *M*, and hence the relation:

$F + M = Z$

when $F = 0$, or $F \approx 0$ (in collapsed fisheries scenario) does not necessarily imply that

$M = Z$.

Rather, either $M \leq Z$, or $M \geq Z$. But M and Z can be very close in the case of collapsed fisheries. M can also be higher than Z since the derivation of Z is independent of M (for instance, Z obtained from length-converted catch model). This is because in collapsed fisheries Z was obtained from sparse length-frequency data due to absence of specimen.

4 Discussions

4.1 Data sources

Environmental data sources were from Marine Fisheries Research Division in Tema, Ghana and Ghana Meteorological Agency over the period 1974-2004. Due to incomplete salinity data in some stations there was a break in the salinity trend from 1984-1995 in the ODV analysis. Nevertheless, the time series analysis of SST, wind speed and salinity along the coast of Ghana for 31-year period in this study is the first of its kind in Ghana and it has provided an insight to the driving force of coastal cooling which has not been fully explained. Since the information is from surface data, it will be more expedient to conduct a detailed oceanographic survey to verify this assertion on cooling in coastal waters of Ghana (Gulf of Guinea). The 1979 unusual high temperature during major cooling does not synchronize with the identified strong wind field in interface I (where weak wind field was expected in that scenario). The 1979 observation in sea temperature and wind is not clear to explain with the available data. Again, the 1986 high landing of triggerfish is inconsistent with the local forcing that prevailed during regime II. Nevertheless, the similarity in sea conditions during interface I (1979) and interface II (1987) suggest that local environmental forcing might have played a crucial role in triggerfish high landings.

Only inshore catch-effort data between 1972 and 1991 (Fig. 13) was reliable enough to be used to assess the fishing pressure on the *Balistes* fishery resource in coastal waters of Ghana. The offshore triggerfish catch was ignored since triggerfish was not the target fish species for the industrial fleets and *Balistes* constitutes just small amount of their by-catch. It was speculated that some industrial trawlers discarded *Balistes* at sea to make room for high price commercial fish species which was their target fish. Again, standardisation of industrial fishing effort with that of inshore was not realistic given the effort information available.
Beach survey for triggerfish samples was not successful. Very few (one or two) triggerfish were recorded at the fish market. Even with the few which was recorded occurred occasionally in the landings of hook and line canoe operators. In fact, there is a general

believe among the fisherfolks in Ghana that the triggerfish has been overexploited. Some triggerfish did occur among "Saeko" landings. Saeko is a fishing practice which is undertaken by some canoe operators who purchase the by-catch of industrial fleets (shrimpers or tuna fleets) sometimes offshore, for sales at the fish market. The triggerfish that occurred in the saeko landings were not suitable for this study as they were usually deep frozen and the fishermen cannot exactly know where the fish was caught. Inability to obtain triggerfish samples from the fish market was not a surprise since the triggerfish fishery has collapsed with only traces of the fish in the artisanal landings. As such, the landing data used were extracted from MFRD annual reports from 1972-2003 which includes Anon. (2003) or JICA report, Koranteng (1998), and Fishbase. Again, triggerfish processed and used in the growth analysis of this study were solely obtained from the catches of the Fridtjof Nansen survey 2005 in the western Gulf of Guinea. Otolith preparation and cutting was a challenge since the shape was irregularly tri-lobe (see Appendix, Fig. 31) and getting the exact plane which may show full growth rings from focus to the margins was a difficult task. It was tried but not really successful, as such ageing of triggerfish was concentrated on 1st dorsal spines (Fig. 22). Ageing was repeated thrice in order to obtain reliable length-age data. The result presented on ageing ignored the counting of marginal dark band as annual ring. However, a marginal light band was considered as annuli since only light bands were counted as annual rings (after Johnson and Saloman 1984). As a result of limited samples of triggerfish from Ghana, size-weight and length-at-age data of triggerfish were pooled from Benin to Côte d'Ivoire. For size-weight analysis, all 84 specimens of *B. capriscus* were used, that of *B. punctatus* were 43. Age determination of *B. capriscus* was possible in only 66 out of 74 spine slides that were clear to read. 31 out of 41 spine slides were used for the determination of age in *B. punctatus*. There were differences in the average percent error for ageing in the two species of triggerfish: *B. capriscus* average percent error was 8.1 % whereas that of *B. punctatus* was 6.5 %. The difference might have come from the differences in sample sizes. Low percent error in the reading of spine slides might be attributed to the clarity of the dark and light bands imprinted on the spines. Again, limited sample size might have contributed to these low reading errors. If the triggerfish samples obtained were to be large enough, there would have been likelihood that the reading errors would have increased. Eventhough, the same ageing procedure was used for the ageing of *B. capriscus* and *B. punctatus*, the L_∞ of *B. punctatus* is quite low and does not seem too realistic when compared to that of *B. capriscus*. It is really difficult to ascertain the approximate L_∞ of *B. punctatus* in literature because there are no previous reports of L_∞ on *B. punctatus*.

4.2 Possible reasons for the collapse of ***Balistes capriscus*** resource

4.2.1 *Extreme events of local environmental parameters in coastal waters of Ghana*

One of the questions pursued in the present study was whether there had been marked or extreme events in local forcing for the last three decades in coastal waters of Ghana. It was indicated in ODV analysis that cooling along the coast of Ghana has varied from year to year and it is likely to be controlled by local and remote forcing. Possible local environmental parameters that might influence cooling events in Ghanaian coastal waters are wide range, however, for this study only sea temperature, coastal wind speed and sea salinity were considered. Sea temperature, wind speed and sea salinity were used because of the availability of data for nearly three decades. The remote forcing influence had been previously linked to El Nino-Southern Oscillation (ENSO) in the Pacific (Bakun 1993) and oceanic interconnections between western and eastern parts of Atlantic (Koranteng and McGlade 2001). Houghton (1976) reported on surface temperature conditions further offshore the coast of Ghana and concluded that it does not go below 25 °C and that the cold dense water is only confined to the continental shelf of Ghanaian waters which suggests the effect of wind on Ghanaian waters is more or less coastal rather than offshore. Evidence gathered in this study seems to show indirect relationship of the three local environmental parameters in the ODV analysis. It seems the east coast cooling cell (Figs. 9 a-c) is controlled by high wind speed (Figs. 10 a-c) that dominates east coast of Ghana. This further suggests that the extent of intense cooling along the east coast for a season will depend on the ‘strength’ or speed of the prevailing wind. These strong wind fields at the east coast usually occurred along Tema (415 km) coastline which has direct impact on the SST and therefore, it is likely to have indirect link to abundance of fish (in general) in this area since Tema waters is known to be one of high fish landing areas in Ghana. Detailed time series of hydrographic data (Figs. 9 a-c and 11 a-c) indicates another cooling cell along the west coast which is likely to be controlled by heavy rains in the west coast region which bring about cooling in surface temperatures (and decrease in salinity as indicated in Figs. 11 a-c) during major cooling season along the west coast of Ghana. From ODV analysis in this study it seems the effect of wind on the west coast cooling might not be so important since the wind speed recorded along the western coastal meteorological stations never exceeded 4.0 m/s from 1974 to 2004 (Figs. 10 a-c). This suggests that the intensity of the west coast cooling might depend on the surface water cooling as a result of heavy annual coastal rains in the southwestern forest area of Ghana. These coastal rains which are likely to control the west coast major cooling off Half Assini (30 km) – Takoradi (185 km) waters might have indirect link to the abundance of fish in Half Assini, Axim (105 km), Cape Three Points (135 km) and Takoradi waters.

The 1974, 1983, 1984, 1988-1990, 1996, 1998, 1999, 2003 and 2004 intrusion of warm water during minor cooling season is difficult to explain from the linkages of sea temperature, wind speed and salinity. The exact reasons for differences identified in wind intensities in minor and major cooling periods at the east coast in 1976-1979, 1986, 1988-1990 and 2000 cannot be figured out from the available data of the present study. Again, it is not clear to explain the strong wind fields identified in 1983, 1986 and 2004 that extend further east to Togo coastal waters. The consistent formation of wind-intersection of high ECW and low WCW along Saltpond (270 km) - Winneba (330 km) coastline suggests the occurrence of surface fronts and its persistency from 1974-2004 (see Figs. 10 a-c) indicated in this study, therefore suggests the formation of convergence zone and the link to abundance of fish off Saltpond-Winneba waters (Aggrey-Fynn, in prep.). It is known that surface fronts are delineating boundaries between different surface water types which when persisted over a significant time frame is associated with a convergence zone (Bakun 2006) and the resulting multi-trophic blooming productivity hence possible high abundance and diversity of fish eggs and larvae (Ekau and Verheye 2005).

The three regimes and two interfaces in triggerfish fluctuations are as follows:

-Regime I (pre-1979): triggerfish just attaining “regular” annual catch level; major cooling intensified in 1975, 1976, 1977 and 1978; strong wind fields at the east coast during minor and major cooling in 1975, 1976, 1977 and 1978; high salinity pattern in 1975, 1976, 1977 and 1978 along the east coast and generally low salinity prior to cooling in the west coast end.

-Catch Interface I (1979): triggerfish attained first catch peak; unusual high temperature during major cooling; strong wind fields at the east coast during minor and major cooling; salinity high at the east coast and low prior to cooling.

-Regime II (between 1979 and 1987): annual triggerfish catch attained regular level; “normal” major cooling events in 1984, 1985 and 1986; strong wind fields at the east coast in 1983 and 1986; insufficient salinity data.

-Catch Interface II (1987): triggerfish attained second catch peak; unusual high temperature during major cooling; weak wind fields at the east coast during minor and major cooling; insufficient salinity data.

-Regime III (between 1987 and 2004): triggerfish catch experienced a “sharp” decline; major cooling generally intensified; generally strong wind fields at the east coast in 1988-2004 and unusual wind fields at the west coast in 2001-2004; high salinity at the east coast in 1996-2004.

It was observed that before 1979, triggerfish had just invaded Ghanaian coastal waters and therefore annual landings were highly variable. Also, the species had just gained popularity in Ghana (West Africa) in the early 1970s and it is believed that some fishers discarded the catches at sea in order to make room for high price fish species at that time. Whatever the case might be, the pre-1979 (regime I) landings were in ascendancy to attain the “regular” annual catch level. Pre-1979 regime coincided with the intensification of major cooling in 1975-1978 with its corresponding strong wind fields in 1975-1978 along the east coast of Ghana (Fig. 10-a). The unusual high temperature experienced in 1979 might have played an important role in the high abundance of triggerfish (ie. interface I). The warm sea conditions might have influenced *Balistes* migration behaviour just before or during 1979. There are reports that the triggerfish species migrate to warm offshore waters during intense coastal cooling conditions (Essuman and Diakitĕ 1990). The 1979 catch interface I coincided with strong wind fields at the east coast which is quite difficult to explain from local forcing analysis. Nevertheless, it is likely the wind pattern was influenced by remote forces. Between 1979 and 1987 (regime II), triggerfish landings and cooling events were normalised with the exception of 1986 high landings which is inconsistent with the sea conditions identified in regime II and therefore unclear to explain from ODV analysis. However, there is the possibility that the sea conditions towards the end of 1986 season were much stable and warmer to attract migration of triggerfish to the coastal waters of Ghana. The unusual high temperature experienced in 1987 (interface II) might have played an important role in the high abundance of triggerfish in catch interface II. This interface coincided with weak wind fields during cooling periods (less intense) which was the expected condition for less cooling and that might have attracted migration of the species. In addition, the minimum mean temperature 'raised' in 1979 and 1987; and the difference between the maximum and minimum mean temperatures (Tmax-Tmin) range 'lowered' in 1979 and 1987 (see Fig. 17) might suggest clues about temperature at which migration of triggerfish is induced in coastal waters of Ghana. This therefore suggests that there is a link between local environmental forcing (ie. unusual warm condition, weak upwellings, weak wind fields) and high triggerfish abundance. The similarity in sea conditions during interfaces I and II, and the corresponding peaks in the triggerfish landings depict the importance of temperature in the catch fluctuations of the species. The sharp decline of triggerfish landings from 1988 to 2004 (regime III), and the corresponding sea conditions suggest a possible link in regimes III and I. That is, there are similarities in the local environmental forcing at the collapse phase (regime III) and before or during invasion phase (regime I) of triggerfish in coastal waters of Ghana.

4.2.2 *Relationships between maxima-minima sea temperature and inshore* <u>Balistes</u> *catch*

One of the questions followed in this study was whether the extreme local sea temperature conditions were primarily responsible for the collapse of triggerfish in coastal waters of Ghana. The relationship between maximum mean temperature and *Balistes* catch (Fig. 17A) indicated a possible temperature partitioning (Tp) between *Balistes* catch or biomass increase period (1972-76) and catch decline period (1985-89) in coastal waters of Ghana. Again, it was observed in Fig. 17A that beyond maximum mean critical temperature (Tc = 28.72 °C in 1987) *Balistes* species disappeared from 1988 onwards in Ghanaian waters. There is the likelihood that Tc is the "point-of-no-return" for triggerfish in Ghanaian coastal waters. The point-of-no-return is defined in this study as the maximum mean temperature of the sea beyond which the *Balistes capriscus* fish stocks might have disappeared or re-located as a result of warming sea conditions. It is known that warming in the sea results in forced rise in oxygen demand for marine organisms and also reduction in oxygen solubility (Pörtner and Knust 2007) in the sea. High oxygen demand of fish species in the warming seas will affect aerobic respiration, and the results might be negative effect on growth performance, fish development, fecundity and recruitment (modified from Pörtner and Knust 2007). In this sense, it could be argued that *B. capriscus* fish stocks might have disappeared after the 1987 warming sea conditions and the fisheries resource could not recover afterwards and hence the collapse of triggerfish fisheries in Ghana.

The catch-per-effort and effort relationship (Fig. 14) indicates scenarios where *Balistes* biomass increased from 1972-76 at virtually the same effort; and *Balistes* biomass decreased considerably in 1979-80 with the same effort and again, biomass declined in 1987-88 with slight change in effort. These three scenarios observed in the catch or biomass and effort of *Balistes* in coastal waters of Ghana suggest a possible influence of environment on the biomass increase and decrease in the respective periods. The influence of minimum mean daily temperature and difference between maximum and minimum mean daily temperatures (Tmax-Tmin) on *Balistes* catch cannot be underscored (see Fig. 17 and Table 2). This is because at virtually the same effort employed inshore *Balistes* catch or biomass had increased in 1972-74 or decreased in 1979-80 and 1987-88 with varying ranges of minimum mean daily temperatures and Tmax-Tmin temperatures. Not much influence was observed in maximum mean daily temperature changes with respect to 1972-74 catch increase; and 1979-80 and 1987-88 catch decline as changes in maximum mean daily temperatures were narrow in range (Fig. 17 and Table 2). The range of minimum mean temperature changes was moderate to wide in the periods of increased and decreased *Balistes* catch. The 1987-88 wide decrease in minimum mean temperature range might have affected triggerfish spawning and/or migration pattern and hence the collapse of the resource. Similarly, the range of Tmax-Tmin temperature changes was moderate to wide in triggerfish increased and decreased periods. The 1987-88 wide increase in Tmax-Tmin range might have affected triggerfish spawning and/or migration pattern and therefore the subsequent collapse of the fishery resource.

On the other hand, two possibilities of *Balistes* spawning and recruitment can be deduced from Fig. 17 based on the biology of triggerfish. The first possibility is that if *Balistes* spawned successfully in 1974 at minimum mean temperature of 22.96 °C the stock would have been recruited in 1979 (first catch peak). Again, if spawning was successful in 1983 at minimum mean temperature of 22.76 °C the stock would have been recruited in 1987 (second catch peak). In the case of difference in temperature if *Balistes* spawned successfully in 1974 at temperature difference (Tmax-Tmin) of 5.43 °C the fish stock would have been recruited in 1979; and if spawning was successful in 1983 at Tmax-Tmin of 4.92 °C the fish stock would have been recruited in 1987 (see Fig. 17). Similarly, the second possibility is that if *Balistes* spawned successfully in 1975 at lower minimum mean temperature of 21.45 °C the fish stock would have been recruited in 1979; and successful spawning in 1982 at lower minimum mean temperature of 21.81 °C the fish stock would have been recruited in 1987. In the case of temperature difference if *Balistes* spawned successfully in 1975 at higher temperature difference of 6.59 °C the fish stock would have been recruited in 1979; whereas a successful spawning in 1982 at higher temperature difference of 6.82 °C the fish stock would have been recruited in 1987. Base on the knowledge of the biology of *Balistes capriscus* in coastal waters of Ghana (Ofori-Danson 1981, 1990) and other species of triggerfish eg. *Xanthichthys mento* (Kawase 2003) triggerfish spawning is successful in warm sea conditions. Also, *B. capriscus* larvae and juveniles had been recorded in seven cruises only during summer season in southern Brazilian waters (Matsuura and Katsuragawa 1981). With these evidences the first possibility is more probable to have occurred during *Balistes capriscus* invasion in Ghanaian coastal waters. It was observed that the recruitment is between 4 and 5 years period depending on sea temperature conditions. Ofori-Danson's reproductive studies on *B. capriscus* in Ghana and growth analysis in this study derived that the fish species reach massive maturation stage at approximately age 4-5 which suggests that the recruitment period is likely to be maximum of 5 years. Thus, the influence of minimum temperature and difference between maximum and minimum temperatures might be very important in *Balistes* abundance or catch.

4.2.3 *Possible scenarios of recent low triggerfish catch in coastal waters of Ghana*

Scenario I: Triggerfish migrate offshore

Alternatively, it can be suggested that there was much more stable thermal conditions of the sea during major upwelling periods (as reported by Longhurst 1962 cited by Ofori-Danson 1990) in 1979 and 1987. However, there is evidence in this study that intense cooling had persisted since 1988 to date during major upwelling seasons along the coast of Ghana with no indication of stable conditions (as experienced during 1979 and 1987). This is in agreement with observations of Bakun (1993) that there has been a long-term intensification of coastal upwelling in the Gulf of Guinea that may be related to global climate change. Eventhough Essuman and Diakitě (1990) acknowledged that the occurrence and concentration of triggerfish (like many schooling fish species) are influenced by upwelling and seasonal variations in temperatures of the sea at various depths the report does not elaborate on how this actually can occur. Nonetheless, the reports on migration of triggerfish from cold coastal waters as a result of cooling to join offshore pelagic stock present throughout the year might give an insight to the role of intense cooling or intensification of minor upwelling (in coastal waters of Ghana) in the collapse of triggerfish fishery from 1988 to date.

In this argument, the perceived significance of the intense cooling during upwelling seasons prior to 1979 and after 1987 is its role in the migration of triggerfish from cooler coastal waters to further offshore (warmer) and therefore its importance in the low catches of triggerfish in coastal waters of Ghana for the last two decades. On the other hand, the relevance of unusual high temperatures recorded during major upwelling periods in 1979 (Fig. 9-a) and 1987 (Fig. 9-b) is the sea temperature suitability to attract migration of offshore triggerfish stock to coastal waters. There are reports that average surface temperature during major upwelling season 100 km (in further offshore) is constantly between 25 °C and 26 °C irrespective of the large annual variation in temperature over the continental shelf of Ghanaian waters (Houghton 1976). This suggests there is a possibility that triggerfish which is sensitive to cold might migrate to warmer conditions further offshore during intense coastal cooling. It is therefore perceived that triggerfish might have migrated to further offshore (which are not trawlable by inshore vessels due to uneven and rocky continental margins) or waters of suitable temperature. Again, the minimum mean temperature recorded in Ghanaian waters has been low after 1987 to date which is very much similar to the minimum mean temperatures prior to 1979 (see appendix, Fig. 30). Such cooling condition of sea occurred prior to 1979 invasion of triggerfish and the same is being experienced after 1987 collapse of the species in coastal waters of Ghana.

Koranteng (1984) explained the sharp decline of *Balistes capriscus* landings of inshore trawlers during the cool season in Ghanaian waters as due to gear switch of the inshore operators to purse seining for *Sardinella*. However, this study suggests that the decline in landings might have occurred due to migration of the triggerfish species to further offshore to spawn during this cooling period in Ghana. The recent cooling during major upwelling period is likely to prevent the fish to return to Ghanaian coastal waters for breeding (see ODV SST analysis-Fig. 9 a-c).

Scenario II: Development of eggs and larvae of triggerfish

The second possible scenario is that, the cooling that occurred in recent period (appendix, Fig. 30) is likely to have had a major negative toll on egg development, as Cury and Roy (2002) states that minor changes in the timing or the intensity of a seasonal cycle of an environmental variable can have an important ecological impact. The breeding season of triggerfish which occur in October-December (Ofori-Danson 1990) is a warm period in Ghana and therefore the breeding of the fish species might have been successful during 1974 warm sea conditions to result in 1979 catch peak (see Fig. 9-a). Similarly, the breeding of triggerfish might have been successful in 1982/83 warm sea conditions along the west coast of Ghana (30-185 km) to result in extreme high abundance of triggerfish in 1986/87 (Fig. 9-a and 9-b). There are other reports (Matsuura and Katsuragawa 1981) that larvae and juveniles of grey triggerfish in Southern Brazilian waters only occurred during summer season, a result obtained from seven cruises. Eventhough, some demersal spawners like *Oxymonacanthus longirostris* (Monacanthidae) are able to shift spawning seasons to suit water temperature conditions in order to produce well developed larvae (Kokita and Nakazono 2000) there are no such reports on triggerfishes. Experiments conducted by Kokita and Nakazono on larvae of *O. longirostris* show that larvae which hatched at lower than natural optimal temperature were extremely under developed compared to larvae which hatched in natural optimal temperature conditions (Kokita and Nakazono 2000). Another report shows that larvae that are small and weak are highly susceptible to predation at the onset of exogenous feeding (Blaxter and Hempel 1963). Possible predation on under-developed larvae coupled with low food concentrations (characteristic of tropical waters) and starvation (Kerrigan 1997), may be a contributing factor in the survival of triggerfish larvae in Ghanaian coastal waters in recent times.

Scenario III: High energy cost of triggerfish parental-care in recent cooling conditions

The third possible scenario is that, it is known from studies on species of *Balistes* and other triggerfish such as *Pseudobalistes flavimarginatus, Melichthys niger, Xanthichthys mento and Canthidermis sufflamen* show parental egg care by tending and guarding of eggs which includes fanning and blowing of eggs, and exclusion of intruders (Lobel and Johannes 1980, Ishihara and Kuwamura 1996, Kawase 2003). The energy used by the spawning adult to undertake such activities is likely to be high in the recent cooling periods identified in Ghanaian waters during spawning period of triggerfish. It is also known that breeding in cold temperatures increase the incubation time of embryos, parental care of a single clutch, and the associated metabolic costs to adults, may be increased substantially by spawning at cooler sea temperatures (Richardson *et al.* 1997). This implies the time and energy expend in parental egg care would be high in the phase of recent cooling conditions characterising the spawning period if the species should breed in coastal waters of Ghana.

This high energy cost in breeding at low temperature conditions might have caused *Balistes capriscus* off Ghana to migrate to more suitable and energy-efficient breeding site. Evidences from this study show that there is no doubt that understanding the seasonal and interannual fluctuations of local forcing and continuous monitoring of their fluctuations will help to better regulate the triggerfish resource should they invade Ghanaian coastal waters when sea conditions become suitable once again.

4.2.4 *Size distribution and growth of* Balistes

Another question pursued in the present study was to assess whether the growth parameters of triggerfish had changed as a result of its disappearance for nearly two decades in comparison with its growth during the dominance period. For size distribution of grey triggerfish in this study, the modal size classes for the samples collected in the period of May 2005 during Nansen survey were 27.0-31.9 and 32.0-36.9 cm *TL*. This is comparable to previously reported modal size of grey triggerfish in Ghanaian coastal waters which stood at 18.0 cm *FL* in June from sample size of 194, 22.5 cm *FL* in July from sample size of 152 and 18.0-23.0 cm *FL* in August from sample size of 364 (Ofori-Danson 1981). It is likely that this modal size class of grey triggerfish dominates the western Gulf of Guinea waters from May – August every season.

In general, there were size and weight differences in *Balistes capriscus* and *B. punctatus*. The mean lengths and weights obtained in the western Gulf of Guinea were different in both species of triggerfish. The differences in the mean weights might be due to the fact that total weights were used. The weight of individual fish might have been influenced by the fullness of the stomach at the time of capture. Again, the fact that length-weight data in the analysis was pooled from Benin to Côte d'Ivoire could also have affected the mean results. Size-weight relationships of grey and blue-spotted triggerfish (Figs. 20 and 21) indicate that for a given size grey triggerfish tends to weigh less than blue-spotted triggerfish. However, in both size-weight equations the exponent for length is sufficiently close to 3.0, a situation which indicates that *B. capriscus* and *B. punctatus* grow symmetrically or isometrically. In both species the size-weight relationships show a good fit to the exponential curve.

Annual increment in both species of triggerfish (Tables 3 and 4) follow generally similar growth pattern, that is to say, annual increment wider at annuli 1 to 2 signifying faster growth at juvenile stage, annual increment narrower from annuli 3 to 6 or 7 signifying slower growth, and annual increments become virtually the same from annuli 10 and 11 signifying constant growth. The significance of small variation in length at lower annuli of *B. punctatus* (Table 4) and that of *B. capriscus* (Table 3) is the fact that both species of triggerfish grow faster at juvenile stage, and growth slows down at adult stage. High variation in length of *B. capriscus* at annuli 1, 2 and 6 might be due to the fish growing under different environmental conditions since samples were pooled from Benin-Côte d'Ivoire.

The maximum size (520-mm *TL*) of grey triggerfish observed in this study was higher than that previously reported. Maximum size reported for grey triggerfish was 350-mm *FL* (Ofori-Danson 1981) in coastal waters of Ghana. The increase in maximum size in this study might be due to the fact that grey triggerfish has not been a target fish for the artisanal fishery since its collapse in the late 1980s, and therefore the fish is able to live for quite a long period of time before it risks the chance of being caught. The maximum size observed in this study might be due to the length-data pooled from Benin to Côte d'Ivoire (that is, western Gulf of Guinea). Also Ofori-Danson used fork length of the fish to estimate maximum size whereas a total length was used in this study. Gear selectivity probably might explain the difference in maximum length as specimen for this study were collected during Fridtjof Nansen survey 2005 using different set of gear from that of the previous reporters. The maximum age of triggerfish in this study was age 11, although Johnson and Saloman (1984) reported on higher ages of 12 and 13 in the Gulf of Mexico, probably our trawls excluded older fish from samples. The back-calculated lengths for grey triggerfish in this study were much comparable to results obtained by Johnson and Saloman (1984) on the same fish species from northeastern Gulf of Mexico. Manooch and Drennon (1987) back-calculated data on queen triggerfish from U.S. Virgin Islands and Puerto Rico seem most similar to that of this study.

The asymptotic length, L_∞ was greater and rate of growth, K slower than previously reported for the grey triggerfish in Ghana (Table 5). Nevertheless, the rate of growth was comparable to that previously reported for grey triggerfish in Côte d'Ivoire (0.11 $year^{-1}$) and Senegal (0.31 $year^{-1}$) (Caverivière 1982). The high L_∞ in this study might have been obtained as a result of the length-age data pooled for the samples in the western Gulf of Guinea. This might suggest that the rate of growth and maximum size of grey triggerfish in the western Gulf of Guinea had not actually changed despite the disappearance of the fish species in West Africa for nearly two decades.

Eventhough, only 23 out of 165 stations trawls yielded triggerfish during the Fridjtof Nansen survey 2005 in western Gulf of Guinea the distribution of 127 triggerfish (*B. capriscus* and *B. punctatus*) obtained showed a suggestive habitat segregation or overlap (Fig. 16) between the two species in the Gulf of Guinea. No immediate explanation could be attributed to the observed pattern of distribution in the two species of *Balistes* in western Gulf of Guinea. However, it could be said that the high growth rate observed in *B. punctatus* could be the result of its occurrence in shallow coastal waters as compared to that of *B. capriscus*. It is likely that the warm shallow coastal waters increase *B. punctatus* metabolic rate, increase demand for oxygen and therefore, growth rate increase. L_∞ of *B. capriscus* was estimated to be 45.081 cm and that of *B. punctatus* was 28.266 cm from observed length-at-age data. This discrepancy between L_∞ of the two species of *Balistes* could be attributed indirectly to the observed differences in depth range or habitat segregation (Fig. 16) in the western Gulf of Guinea. Eventhough, there were not much differences in the diet of *B. capriscus* and *B. punctatus* (Tables 6-9) the L_∞ discrepancy could however, be attributed to the effect of the warmer sea conditions that might prevail at the shallow waters (22-32 m depth) for *B. punctatus,* and colder deep coastal waters (up to 60m depth) for *B. capriscus*. It could also be the effect of fishing pressure from inshore trawlers in shallow waters of western Gulf of Guinea on *B. punctatus* that might have resulted in "stunted" growth in the fish species and therefore the *Lmax* is relatively low. The triggerfish species, *B. capriscus* was found to be occupying wide range of depth (23-60 m) in coastal waters of western Gulf of Guinea (see Fig. 16), and therefore, with the species disappearance its wide depth distribution is likely to have reduced the fishing pressure on *B. capriscus* since its collapse.
Again, with the observation in distribution of triggerfish in western Gulf of Guinea *B. capriscus* and *B. punctatus* are segregated by depth in their habitat. Both triggerfish species

are more planktivorous at juvenile stage (12.0-21.9 cm size class) and more benthivorous at later stage in life. There could be competition for food resources (benthic macroinvertebrates) between the two fish species at the later stage of their development. However, it appears *B. capriscus* is better adapted in terms of benthic life as the species occur at deeper depth of coastal waters and therefore, better selected for benthic feeding. In addition, it could be that *B. capriscus* has a comparatively better foraging ability than *B. punctatus* since *B. capriscus* has a wider and deeper habitat range and its foraging might be more independent of light and temperature than that of *B. punctatus*. For these reasons, *B. capriscus* might have a competitive advantage over *B. punctatus* at benthivorous stage. In that sense, *B. punctatus* growth at later stage might be affected negatively and hence stunting could result in *B. punctatus*.

4.2.5 *Mortality and rate of exploitation*

Another pursued question was to find out whether the exploitation of triggerfish has contributed to the collapse of the resource. The reported natural mortality, M from Ofori-Danson (1981) was higher (0.81) on Ghana triggerfish stock than that estimated for grey triggerfish (0.5178) in this study. However, M estimate (0.39) from Caverivière (1982) of grey triggerfish in Senegal waters was quite comparable to value obtained in this study. The observation that M in many cases was higher than Z (Tables 10 and 11) could be true in the sense that Z was mostly low because the triggerfish fisheries had collapsed or the triggerfish stocks had disappeared and therefore, the fishing mortality (F) is very low or almost insignificant or “absolutely” negligible. For this reason, the mortality of triggerfish was mainly dependent on the natural causes rather than the fishing activities on the resource since the last two decades (after the collapse). This means M is likely to be very close to and /or equal to Z (that is, $M \leq Z \leq M$) since the fisheries of the triggerfish resource had not revamped. In addition, the estimation of Z from sparse length-distribution data (Figs. 18 and 29) of already collapsed fisheries might have been the probable cause of low value for Z in this study. Again, there is no previous report on M for blue-spotted triggerfish, nonetheless this study estimated M = 0.8615 using Pauly's M equation for the observed data of blue-spotted triggerfish.

The exploitation ratios of grey triggerfish show under-exploitation (Tables 10 - 12) of the fish in western Gulf of Guinea, when growth parameters from all back-calculated including end-points and weighted mean back-calculated data were used. This observed exploitation levels might be due to the shift of focus on the resource due to its collapse for the past two decades. It could also be said that overfishing might not have played a major role in the collapse of triggerfish in Ghana and western Gulf of Guinea considering the revelation that the resource is currently under-exploited. Comparing current exploitation levels of *Balistes capriscus* to that of 1980 (E = 0.67 -see appendix, Fig. 32) which was near over-exploitation indicate that the resource is still viable in Ghana. The likely question to be asked is that if the resource is presently under-exploited why is the fishery of *Balistes* not revived in Ghana again? The probable answer might come from local environmental forcing point of view. Considering the fact that there has been intense cooling along the coast of Ghana in recent years (see appendix, Fig. 30) and that triggerfish migrate from cold coastal waters to warm offshore waters (possibly because they are temperature sensitive) and the fact that the unusual minimum mean temperatures experienced in 1979 and 1987 (that possibly triggered their migration) have not been recorded again in coastal waters of Ghana might be the probable answer for this puzzle.

Despite the slight changes in L_∞ and K in both the western and eastern stocks of grey triggerfish, the growth performance index of the species has remained virtually the same in both periods of its dominance and collapse in West African waters (Table 5). There were no previous reports on growth performance index for blue-spotted triggerfish nonetheless this study obtained values comparable to that of grey triggerfish in Côte d'Ivoire (Table 5). The growth performance index represents and quantifies the energetics of a habitat which is directly related to growth performance and hence the link to food consumption and metabolism of a fish (Munro and Pauly 1983).

The major food items identified in the gut of *Balistes capriscus* and *B. punctatus* were comparable to the results of earlier studies on main food items of *Balistes capriscus* in Ghanaian coastal waters which were marine crustaceans and molluscs (Ofori-Danson 1981). The diet composition of *B. capriscus* and *B. punctatus* (Tables 6-9) were zooplankton in the juvenile stage and macrobenthic invertebrates and vertebrates such as fish at the adult stage. The main food items of crustaceans and molluscs in the dominance period remains quite important in the diet of *B. capriscus* and *B. punctatus* even in the collapse period of the triggerfish fisheries. The presumed prey of triggerfish abundant in Ghanaian waters and Gulf of Guinea are Marine crabs, Tropical spiny lobsters, *Penaeus* shrimps, Natantian decapods, Cuttlefish and various Squids. Eventhough triggerfish has virtually disappeared for almost two decades there is a continuous increase in abundance of the “presumed” main diet (especially, cuttlefish) in Ghanaian coastal waters (Fig. 27). It seems there is an explosion of cuttlefish population with the absence of the main predator, triggerfish. The increase is not really obvious in other prey items such as marine crabs. This could be explained that there might be other predators as well preying upon them in Ghanaian waters. Also, it is likely cuttlefish is preying upon natantian decapods to control its population even with the absence of triggerfish since 1988 to date.

The result and data analysis presented here may not be sufficient to provide conclusive evidence supporting the hypothesis that collapse or disappearance of *Balistes capriscus* may have been caused by extreme events of sea temperature, coastal wind speed and sea salinity in coastal waters of Ghana. Nevertheless, there were significant qualitative evidences to show that sea temperature and triggerfish catch are linked; and the study provides insights into the coastal hydrography of Ghana for the last three decades which could be used to explain the fluctuations in coastal fishery resources more especially, pelagics. Again, there were some evidences that triggerfish exploitations in the early 1980s was closer to optimum level but that was not strong enough to conclude that exploitation of triggerfish might have contributed significantly in the sudden collapse of triggerfish resource in Ghana and the entire western Gulf of Guinea.

5 CONCLUSIONS AND RECOMMENDATIONS

- The three decades of hydrographic data analysed in this study provides leads or insights into coastal wind pattern and extreme events in sea temperature which might be very useful to fishery scientist to interpret other unexplained fisheries and oceanographic events (such as the out-of-phase fluctuations of *Sardinella* and triggerfish) that had occurred in Ghanaian coastal waters. The time series analysis of SST, wind speed and salinity along the coast of Ghana for 31-year period in this study might be the first detailed analysis of oceanographic data in Ghana. Since the information is from surface data, it will be more expedient to conduct a detailed oceanographic survey to have in-depth understanding of the Ghanaian coastal water system and how it affects fisheries.

- The regimes of triggerfish had not been reported in the region, western Gulf of Guinea. The three regimes and two catch interfaces of triggerfish identified and their corresponding local environmental forcing suggest the influence or control of sea temperature on *Balistes capriscus* fishery resource. There were some evidences that the extreme maximum sea temperatures recorded in 1988 (after maximum critical temperature in 1987) might have been the cause of *B. capriscus* disappearance in Ghanaian waters.

- It was quite difficult to explain some of the inconsistencies in the pattern of ODV analysis of SST, wind speed and salinity from the available local environmental data. For instance, the 1974, 1983, 1984, 1988-1990, 1996, 1998, 1999, 2003 and 2004 intrusion of high temperatures during minor upwelling do not correspond always with the coastal wind speed trend in the respective seasons. It is likely that local forcing is influenced by remote forcing such as Pacific ENSO and/or western and eastern Atlantic interconnections.

- Changes in sea temperature observed may have affected triggerfish populations either temporary or more permanently (Désaunay *et al*. 2006) through recruitment processes, adult re-location and spawning. From all indications in the data analysis of triggerfish catch and sea temperatures, if triggerfish migrate from cold waters to warmer waters then until mean minimum sea temperature in Ghanaian coastal waters become suitable (just as recorded in 1979 and 1987) the invasion of triggerfish might not be experienced in Ghana again. And the fishermen will continue to wonder the whereabouts of triggerfish.

- Eventhough the triggerfish resource was exploited in 1970s and 1980s, overfishing might not have played any important role in the collapse of *Balistes capriscus* in Ghana since this study did not identify adverse exploitation levels of the fish species in western Gulf of Guinea.

- Again, the fact that exploitation ratios in *Balistes capriscus* show under-exploitation might suggests that the resource had not been a target for the fisheries since its collapse for nearly two decades.

- The three local environmental forcing (sea temperature, coastal wind speed and salinity) considered in this study needs to be monitored together with the *Balistes capriscus* landings continuously in future for prompt noticing of resurgence of the species when the sea conditions become more suitable.

- Fieldwork confirmed that the reported captured depth range (15-60 m) of *Balistes* had not changed as this study recorded depth range of 22-60 m for *Balistes*. It was observed that *Balistes punctatus* occurred in shallow water depths (22-32 m) as compared to *B. capriscus* depth range (23-60 m) in western Gulf of Guinea. Further studies will be recommended for the seemingly habitat (depth) segregation or overlap between *B. capriscus* and *B. punctatus* in the western Gulf of Guinea.

- L_∞ and K for *Balistes punctatus* had not been reported in earlier works of triggerfish. Further distribution, growth and reproductive studies would be recommended on *Balistes punctatus* since very little of the biology of this species is known in the western Gulf of Guinea.

- The relationship: $F + M = Z$ needs to be reconsidered in different fisheries scenarios. This is because in the case of collapse fisheries, if $F = 0$ (or $F \approx 0$) $M \neq Z$ in nature. It should therefore, be figured out that under which natural mortality possibilities in fisheries collapsed scenario that: $M \leq Z \leq M$.

- The zoo- and ichthyoplankton community in the identified wind intersection area off Saltpond-Winneba (270-330 km) need to be considered in future studies to help for better understanding of the ecology of this highly productive area.

6 REFERENCES

Aggrey-Fynn, J. (in prep.). Comparison of demersals in western Gulf of Guinea on either side of Winneba-Saltpond (Ghanaian waters) wind-intersection zone.

Ajayi, T.O. 1994. The status of the marine fisheries resources of the Gulf of Guinea. A paper presented at the tenth session of CECAF Working Party on Resources Evaluation held in Accra, Ghana, 10 – 13 October, 1994. CECAF/RE/94/2 Add. September, 1994: 16p.

Anon. 2003. Stock Assessment of Demersal Fish Species in the Republic of Ghana. Final report: Data book, Japan International Cooperation Agency (JICA), 233p.

Bakun, A. 1993. Global climate variations and potential impacts on the Gulf of Guinea *Sardinella* fishery. Dynamics and use of Sardinella resources from upwelling off Ghana and Ivory Coast (Dynamique et usage des resources en Sardinelles de l'upwelling cotier du Ghana et de Cote D'Ivoire), ORSTOM, Paris (France), 1993, pp. 60 – 84.

Bakun, A. 2006. Fronts and eddies as key structures in the habitat of marine fish larvae: opportunity, adaptive response and competitive advantage. pp. 105-122. In: *Recent Advances in the study of Fish eggs and Larvae*. M.P. Oliver and J.J. Govoni (eds.). Scientia Marina, **70(S2):** October 2006, Barcelona, Spain.

Bannerman, P.O., Koranteng, K.A. and C.A. Yeboah 2001. Ghana Canoe Frame Survey 2001. Information Report No. 33, Marine Fisheries Research Division, Tema, Ghana, 35p.

Binet, D. and E. Marchal 1993. The Large Marine Ecosystem of shelf areas in the Gulf of Guinea: Long-term variability induced by climatic changes. In: *Large Marine Ecosystems: Stress, Mitigation and Sustainability*. K. Sherman, L. M. Alexander, B.D. Gold (eds.) AAAS publication, pp. 92-395.

Blaxter, J.H.S. and G. Hempel 1963. The influence of eggs size on herring larvae (*Clupea harengus*). *J. Cons int Explor Mer* **28:** 211-240.

Boltovskoy, D. 1999. South Atlantic Zooplankton. Vol. 1. Backhuys Publishers, Netherlands, pp. 1-868.

Boltovskoy, D. 1999. South Atlantic Zooplankton. Vol. 2. Backhuys Publishers, Netherlands, pp. 869-1706.

Caverivière, A. 1982. The West African Triggerfish (*Balistes carolinensis*). Biology, proliferation and potential exploitation. *Oceanologica Acta* **5(4)**: 453 - 459.

Cury, P., Bakun, A., Crawford, R.J.M., Jarre, A., Quiňones, R.A., Shannon, L.J. and H.M. Verheye 2000. Small pelagics in upwelling systems: patterns of interaction and structure changes in 'wasp-waist' ecosystems. ICES Journal of Marine Science 57: 603-618.

Cury, P. and C. Roy 2002. Environmental Forcing and Fisheries Resources in Côte d'Ivoire and Ghana: Did Something Happen? *In* J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources.* Elsevier, Amsterdam.

Désaunay, Y., Guérault, D., Le Pape, O. and J.-C. Poulard 2006. Changes in occurrence and abundance of northern/southern flatfishes over a 20-year period in a coastal nursery area (Bay of Vilaine) and on the eastern continental shelf of the Bay of Biscay, p. 193-200. *In* X.A.G. Morán, J.M. Rodríguez and P. Petitgas (eds.). Oceanography of the Bay of Biscay, *Scentia Marina* **70S1,** Barcelona, Spain.

Dulčić, J., Kršinić, F., Kraljević, M. and A. Pallaoro 1997. Occurrence of fingerlings of grey triggerfish, *Balistes carolinensis* Gmelin, 1789 (Pisces: Balistidae), in the Eastern Adriatic. *Ann. An. Istrske Mediter. Stud. (Hist. Nat.).* **Vol. 7,** pp. 271-276.

Ekau, W. and H.M. Verheye 2005. Influence of oceanographic fronts and low oxygen on the distribution of ichthyoplankton in the Benguela and southern Angola currents. *African Journal of Marine Science,* **27(3):** 629-639.

Essuman, K. 1989. A review of production and utilization of triggerfish in Ghana. FAO Fish. Rep./FAO Rapp. Peches (Supplement), pp. 207-212.

Essuman, K. and B. Diakitě 1990. Utilization of triggerfish (*Balistes carolinensis* = *B. capriscus*) in Ghana and Senegal. FAO Fisheries Circular No. 828, 23p.

Food and Agriculture Organisation (FAO) 1998. FAO Fisheries Department,Fishery Country Profile, The Republic of Ghana.(http:/www.fao.org/fi/fcp/ghane.asp).

FAO 1983. Fishery Statistics: Capture production 1981. FAO Fisheries Series No. 18, FAO Statistics Series No. 45, Vol. 52, 357p.

FAO 1986. Fishery Statistics: Capture production 1984. FAO Fisheries Series No. 25, FAO Statistics Series No. 65, Vol. 58, 451p.

FAO 1996. Fishery Statistics: Capture production 1994. FAO Fisheries Series No. 46, FAO Statistics Series No. 128, Vol. 78, 699p.

FAO 2005. Fishery Statistics: Capture production 2003. FAO Fisheries Series No. 69, FAO Statistics Series No. 180, Vol. 96/1, 664p.

FAO 2006. Fishery Statistics: Capture production 2004. FAO Fisheries Series No. 72, FAO Statistics Series No. 190, Vol. 98/1, 560p.

FAO-ICLARM Fish Stock Assessment Tools (FiSAT). December 2006. Available at: http:// www.fao.org/fi/statist/fisoft/fisat/index.htm (last accessed 16 February 2007).

Froese, R. and D. Pauly (eds) (2006). FishBase. World Wide Web electronic publication. http://www.searoundus.org/eez/eez.aspx , version (09/2006).

Fishery Research Unit (FRU) 1981. Report for the Triennium 1977-1979 on the Research and Utilization Branch of the Fisheries Department, Tema Ghana, 82p.

Fishery Research Unit (FRU) 1983. Report for the Triennium 1980-1982 on the Research and Utilization Branch of the Fisheries Department, Tema Ghana, 34p.

Gayanilo Jr., F.C. and D. Pauly (eds) (1997). The FAO-ICLARM Stock Assessment Tools (FiSAT) Reference Manual. FAO Computerized Information Series (Fisheries), Vol. 8, FAO, Rome.

Gibbons, M.J. 2000. An introduction to the zooplankton of the Benguela current region. NBD, Western Cape, 50p.

Hardman-Mountford, N.J. and J.M. McGlade 2002. Defining Ecosystem Structure from Natural Variability: Application of Principal Components Analysis to Remotely Sensed Sea Surface Temperature. *In* J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources.* Elsevier, Amsterdam.

Hela, I. And T. Laevastu 1961. Fisheries Hydrography: How Oceanography and Meteorology can and do serve Fisheries. London: Fishing News, 137p.

Houghton, R. W. 1976. Circulation and Hydrographic Structure over the Ghana Continental Shelf during the 1974 Upwelling. Journal *of Physical Oceanography*, **6:** 909-924.

Hyslop, E.J. 1980. Stomach contents analysis – A review of methods and their application. *Journal of Fish Biology*, 17: 411-429.

IMR 1989. Surveys of the Small Pelagic Fish Resources of Côte d'Ivoire and Ghana, 12-20 October, 1989. Institute of Marine Research (IMR), Bergen, Norway. 9p.

Ishihara, M. and T. Kuwamura 1996. Bigamy or monogamy with maternal egg care in the triggerfish, *Sufflamen chrysopterus*. *Ichthyological Research*, **43(3):** 307-313.

Kawase, H. 2003. Spawning behaviour and parental egg care of the crosshatch triggerfish, *Xanthichthys mento* (Balistidae). *Environmental Biology of Fishes* **66:** 211-219.

Joanny, T. and F. Ménard 2002. Analysis of the Spatial and Temporal Variability of Demersal Communities of the Continental Shelf of Côte d'Ivoire. *In* J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources.* Elsevier, Amsterdam.

Johnson, A.G. and C.H. Saloman 1984. Age, growth, and mortality of gray triggerfish, *Balistes capriscus,* from the northeastern Gulf of Mexico. *Fishery Bulletin,* **82(3):** 484-491.

Jones, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data. FAO Fisheries Technical Paper, No. 256. Rome, 118p.

Kawai,H., Yatsu,A., Watanabe,C., Mitani, C., Katsukawa,T., & H. Matsuda 2002. Recovery policy for chub mackerel stock using recruitment-per-spawning. *Fisheries Science*, **68:**963-971.

Kerrigan, B.A. 1997. Variability in larval development of the tropical reef fish *Pomacentrus amboinensis* (Pomacentridae): the parental legacy. *Mar Biol* **127:** 395-402.

Kokita, T. and A. Nakazono 2000. Seasonal variation in the diel spawning time of the coral reef fish *Oxymonacanthus longirostris* (Monacanthidae): parental control of progeny development. *Mar Ecol Prog Ser* **199:** 263-270.

Koranteng, K.A. 1994. A Trawling Survey off Ghana 1981-1982. FAO-CECAF Project, CECAF/TECH/84/63.December 1984, Dakar, 70p.

Koranteng, K.A., McGlade, J.M. and B. Samb 1996. A Review of the Canary Current and Guinea Current Large Marine Ecosystems. pp. 61 – 81. *In*: ACP – EU Fisheries Research Report No. 2. ISSN 1025.

Koranteng, K.A. 1998. The impacts of environmental forcing on the dynamics of demersal fishery resources of Ghana. Ph.D Thesis, University of Warwick. 377p.

Koranteng, K.A. and J.M. McGlade 2001. Climatic trends in continental shelf waters off Ghana and in the Gulf of Guinea, 1963-1992. *Oceanologica Acta*, **24(2):** 187-198.

Koranteng, K.A. 2002. Fish Species Assemblages on the Continental Shelf and Upper slope off Ghana. *In* J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources.* Elsevier, Amsterdam.

Lobel, P.S. and R.E. Johannes 1980. Nesting, eggs, and larvae of triggerfishes (Balistidae). *Env. Biol. Fish.*, **5(3):**251-252.

Longhurst, A.R. and D. Pauly 1987. Ecology of Tropical Oceans. Academic Press: New York, London, Sydney, Toronto. 407p.

Manooch III, C.S. and C.L. Drennon 1987. Age and growth of yellowtail snapper and queen triggerfish collected from the U.S. Virgin Islands and Puerto Rico. *Fisheries Research*, **6:** 58-68.

Marine Fisheries Research Division (MFRD) 1988. A Review of the Oceanography and Fisheries Resources in the coastal waters of Ghana, 1981-1986. Fisheries Department, Research and Utilization Branch, Tema Ghana, 35p.

Marine Fisheries Research Division (MFRD) 1990. Report for the triennium 1983-1985 on the Research and Utilization Branch of the Fisheries Department, Tema Ghana, 46p.

Marine Fisheries Research Division (MFRD) 1993. Occurrence of demersal fish species off Winneba and Saltpond: Their abundance and distribution in relation to the marine environment. Mar. Fish. Res. Rep. N°9, Tema Ghana, 88p.

Marine Fisheries Research Division (MFRD) 2002. Focus on the marine fisheries research division. Directorate of Fisheries, Ministry of Food and Agriculture, Ghana, 8pp.

Matsuura, Y. and M. Katsuragawa 1981. Larvae and Juveniles of Grey Triggerfish, *Balistes capriscus,* from Southern Brazil. *Japanese Journal of Ichthyology*, **28(3):** 267-275.

Mehl, S., Alvheim, O. and S.N.K. Quaatey 2004. Surveys of the fish resources of the western Gulf of Guinea (Benin, Togo, Ghana, Cote d'Ivoire). Survey of the pelagic and demersal resources 14 May-08 June 2004. NORAD-FAO/UNDP project GCP/INT/730/NOR. Cruise reports Dr. Fridtjof Nansen, Institute of Marine Research, Bergen, Norway, 59p.

Mehl, S., Olsen, M. and P.O. Bannerman 2005. Surveys of the fish resources of the western Gulf of Guinea (Benin, Togo, Ghana, Cote d'Ivoire). Survey of the pelagic and demersal resources 03-29 May 2005. NORAD-FAO/UNDP project GCP/INT/730/NOR. Cruise reports Dr. Fridtjof Nansen, Institute of Marine Research, Bergen, Norway, 63p.

Mendo, J., Pizarro, L. & S. Castillo 1987. Monthly turbulence and Ekman transport indexes 1953 to 1985, based on local wind records from Trujillo and Callao, Peru, p. 75 – 88. *In* D. Pauly and I. Tsukayama (eds.) The Peruvian anchoveta and its upwelling ecosystem: three decades of change. ICLARM Studies and Reviews 15, 351p. Instituto del Mar del Peru (IMARPE), Callao, Peru; Deutshe Gesellschaft für Technishe Zusammenarbeit (GTZ), GmbH, Eschborn, Federal Republic of Germany; and International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

Mensah, M.A. and S.N.K. Quaatey 2002. An Overview of Fishery Resources and Fishery Research in the Gulf of Guinea. *In* J.M. McGlade, P. Cury, K.A. Koranteng and N.J. Hardman-Mountford (eds). *The Gulf of Guinea Large Marine Ecosystem: Environmental Forcing and Sustainable Development of Marine Resources.* Elsevier, Amsterdam.

Moku, M., Kawaguchi, K., Watanabe, H. and A. Ohno 2000. Feeding habits of three dominant myctophid fishes, *Diaphus theta*, *Stenobrachius leucopsarus* and *S. nannochir*, in the subarctic and transitional waters of the western North Pacific. *Marine Ecology Progress Series* **207:** 129 – 140.

Moore, D. 1967. Triggerfishes (Balistidae) of the western Atlantic. *Bull. Mar. Sci.* **17(3):** 689-722.

Munro, J.L. and D. Pauly 1983. A simple method for comparing the growth of fishes and invertebrates. ICLARM Contribution No. 157. *Fishbyte,* p.5-6.

Nakayama,S., Masuda,J., Shoji,J., Takeuchi,T. & M. Tanaka 2003. Effect of prey items on the development of schooling behaviour in chub mackerel *Scomber japonicus* in the laboratory. *Fisheries Science*, **69:** 670-676.

Newell G.E. and R.C. Newell 1977. Marine Plankton: A practical Guide. Hutchison, London, UK.

Ofori-Adu, D.W. 1987. A note on the Problem of the Triggerfish Fishery in Ghana. Marine Fisheries Research, Special Paper No. 1, Fisheries Department, Research and Utilization Branch, Tema, Ghana p. 7.

Ofori-Adu, D.W. 1994. Where is Ewura Efua – The Triggerfish? *The Fisherman.* A Bi-annual Newsletter of the Fisheries Department, Ministry of Food & Agriculture, Ghana. p.13-16.

Ofori-Danson, P.K. 1981. The Biology of the Triggerfish, *Balistes capriscus* in Ghanaian Waters. MSc thesis, University of Ghana, Legon, 98p.

Ofori-Danson, P.K. 1989. Growth of Grey Triggerfish, *Balistes capriscus*, Based on Growth Checks of the Dorsal Spine. *Fishbyte*, **7(3):** 11-12.

Ofori-Danson, P.K. 1990. Reproductive ecology of the Triggerfish, *Balistes capriscus* from the Ghanaian coastal waters. *Tropical Ecology* **31 (1):** 1-11.

Oliver, P. and J. Miquel 1987. Report on the Survey carried out by the R/V Cornide de Saavedra in the Gulf of Guinea in 1986. Instituto Espanol de Oceanografia, Palma de Mallorca.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer., **39(3):** 175-193.

Pauly, D. 1983a. Length-converted catch curves. A powerful tool for fisheries research in tropics. (Part I). *ICLARM Fishbyte*, **1(2):** 9-13.

Pauly, D. 1983b. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. **234:** 25pp.

Pauly, D. and J.L. Munro 1984. Once more on the comparison of growth in fish and invertebrates. ICLARM Contribution No. 195. *Fishbyte* **2(1):** 21.

Pezennec, O. 1984. Ecological importance of the Ivorian and Ghanaian minor upwelling season. FAO technical report, Conakry (Guinea), 11p.

Pezennec, O. and K.A. Koranteng 1998. Changes in the dynamics and biology of small pelagic fisheries off Côte d'Ivoire and Ghana: An ecological puzzle. pp. 329-343. *In*: M. H. Durand, P. Cury, R. Mendelssohn, C. Roy, A. Bakun and D. Pauly (eds.). *Global versus local changes in upwelling systems.* Editions ORSTOM Paris.

Pielou, E.C. 1984. The interpretation of ecological data: A primer on classification and ordination. John Wiley & Sons, New York, 263p.

Pörtner, H.O. and R. Knust 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science*, **315**, 95-97.

Richardson, D.L., Harrison, P.L. and V.J. Harriott 1997. Timing of spawning and fecundity of a tropical and subtropical anemonefish (Pomacentridae: *Amphiprion*) on a high latitude reef on the east of Australia. *Mar Ecol Prog Ser* **156:** 175-181.

Ruppert, E.E. and R.D. Barnes 1994. Invertebrates Zoology. Sixth Edition. Harcourt College Publishers, New York, pp. 1056.

Saetersdal, G., Bianchi, G., Stromme, T. and S.C. Venema 1999. The Dr. Fridtjof Nansen Programme 1975-1993. FAO Fish. Tech. Paper **391**.

Sazonov, Yu.G. and A.I. Galaktionova 1987. Some data on the morphometrics of the grey triggerfish, *Balistes carolinensis*, of the central-eastern Atlantic. *Journal of Ichthyology*, **Vol. 27, no.3,** pp. 173-176.

Schlitzer, R. 2006. Ocean Data View, version 3.1.0. (http://odv.awi.de)

Sparre, P. and S.C. Venema 1992. Introduction to tropical fish stock assessment. Part I. Manual. FAO Fish. Tech. Papers **306(1):** 376pp.

Stromme, T., G. Saetersdal, and H. Gjosxter 1982. Preliminary report on surveys with the R/V Dr. Fridtjof Nansen in West African waters in 1981. CECAF. Working party on resource evaluation. Ses. 6. Dakar 2-6 February 1982. Bergen.

Stromme, T. 1983. Final Report of the R/V Dr. Fridtjof Nansen Fish Resource Surveys off West Africa from Agadir to Ghana May 1981 - March 1982. A joint NORAD FAO/UNDP project. Institute of Marine Research, Bergen, Norway.

Stromme, T. 1994. Report on the R/V Dr. Fridtjof Nansen Fish Resource Surveys off West Africa: Morrocco to Ghana and Cape Verde. CECAF/ECAF SERIES 84/29. 109p.

7 Appendix

Table 13: Results of canoe frame survey conducted between 1969 and 2001 (Source: Bannerman *et al.* 2001)

Number of	1969	1973	1977	1981	1986	1989	1992	1995	1997	2001
Fishing Villages	198	191	200	174	188	192	189	189	191	185
Landing Beaches	269	257	238	222	276	264	206	310	308	304
Outboard Motors				3698	4250	4631	4262	5076	5139	5256
Fishermen			81000	84100	104700	91400	96400	101700	103340	123156
Number of Canoes for										
Poli/Watsa	2315	2244	3005	3359	3969	3684	3458	3923	3709	2439
Beach Seines	1587	1081	761	833	797	852	775	790	769	813
Line	734	676	1174	661	1004	157	1040	782	920	1134
Lobster Set net						1114	547	402	430	549
Set net	3347	2973	3532	1734	1852	574	1955	2294	2036	2324
Ali						1874	1292	1437	1394	1618
Poli										
Watsa										
Nifa nifa							249	333	332	462
Drifting nets				351	450	366	880	476	414	312
One Man Canoe					142	162	580	327	332	330
Total Canoes	**8728**	**8238**	**8472**	**6938**	**8214**	**8052**	**8688**	**8641**	**8610**	**9981**
% motorised				53.3	51.7	57.5	49.1	58.7	61.2	52.6

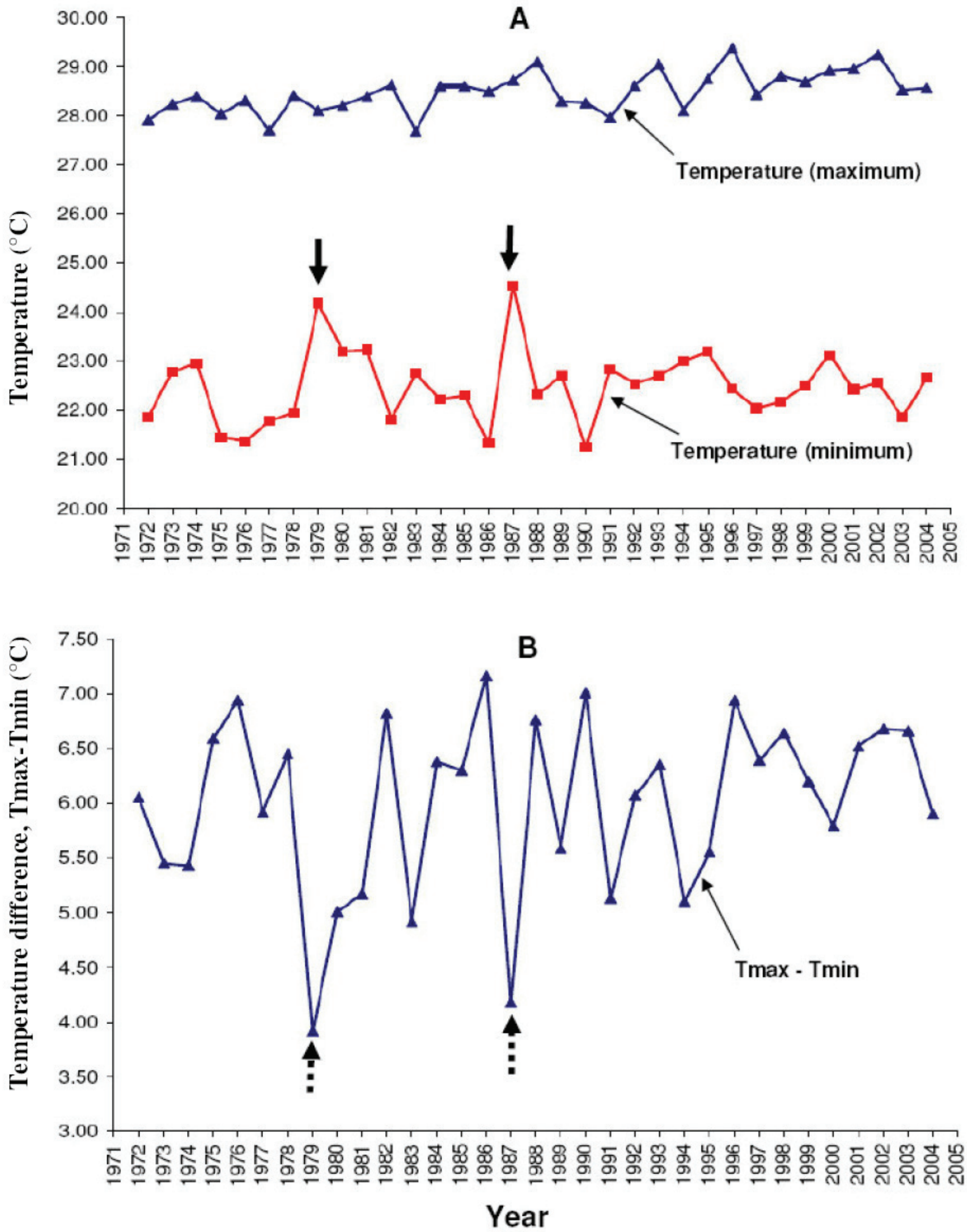


Fig. 30: Time series plots of (A) maximum and minimum mean sea temperatures, and (B) difference in maximum and minimum mean sea temperatures (Tmax-Tmin) over the period 1972-2004 in coastal waters of Ghana. Solid arrows highlight the unusual minimum mean temperatures in 1979 and 1987; broken arrows highlight unusual Tmax-Tmin recorded in 1979 and 1987

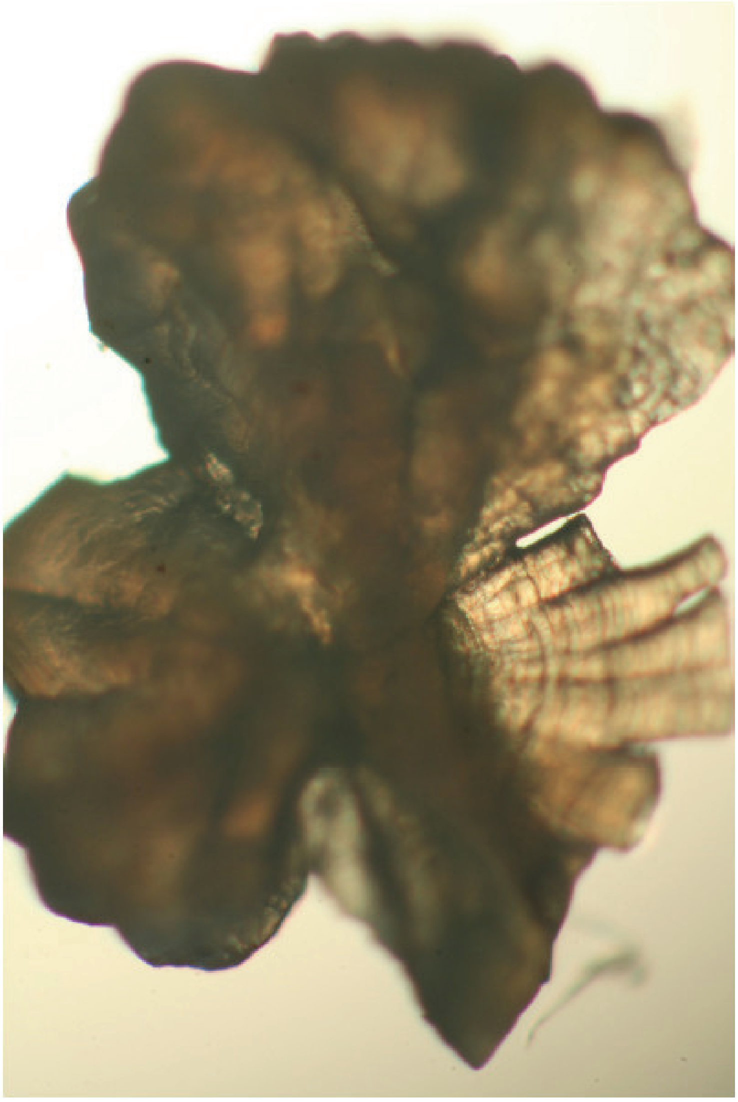


Fig. 31: Image of otolith of *Balistes capriscus* (showing irregular tri-lobe shape)

Table 14: Diet analysis of *Balistes capriscus* – Frequency of Occurrence method

Size class (TL/cm)	12.0 – 21.9			22.0 – 31.9			32.0 – 41.9			42.0 – 52.0		
	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%
No. of Fish	12			26			28			8		
No. of empty guts	1			7			1			0		
No. of non-empty guts	11			19			27			8		
(A) Zooplankton												
Amphipoda: Hyperiids	-	-	**-**	5	0.263	**9.1**	1	0.037	**1.4**	-	-	**-**
Copepoda	-	-	**-**	1	0.053	**1.8**	1	0.037	**1.4**	-	-	**-**
Eupausiidae	-	-	**-**	1	0.053	**1.8**	-	-	**-**	-	-	**-**
Mysidae	1	0.090	**3.0**	-	-	**-**	-	-	**-**	-	-	**-**
Anthomedusa	1	0.090	**3.0**	-	-	**-**	-	-	**-**	-	-	**-**
Jellyfish	-	-	**-**	-	-	**-**	1	0.037	**1.4**	-	-	**-**
Fish larvae (Batoid)	-	-	**-**	-	-	**-**	1	0.037	**1.4**	-	-	**-**
(B) Benthic macroinvertebrates												
Bivalvia	1	0.090	**3.0**	3	0.158	**5.5**	3	0.111	**4.1**	-	-	**-**
Decapoda:												
Brachyura (Crabs)	4	0.364	**12.2**	1	0.053	**1.8**	5	0.185	**6.8**	1	0.125	**4.0**
Nephropidae (Crayfish/Lobsters)	3	0.273	**9.1**	9	0.474	**16.4**	9	0.333	**12.3**	2	0.250	**8.0**
Penaeidae (shrimps)	2	0.182	**6.1**	2	0.105	**3.6**	4	0.148	**5.5**	3	0.375	**12.0**
Sepiida:												
Sepia/Flesh of Sepia	-	-	**-**	2	0.105	**3.6**	4	0.148	**5.5**	6	0.750	**24.0**
Nematoda	1	0.090	**3.0**	4	0.211	**7.3**	6	0.222	**8.2**	2	0.250	**8.0**
Polychaeta	1	0.090	**3.0**	1	0.053	**1.8**	-	-	**-**	-	-	**-**
Volutacea: (Cybium)	-	-	**-**	-	-	**-**	1	0.037	**1.4**	-	-	**-**
Shell of siphonidae	1	0.090	**3.0**	-	-	**-**	-	-	**-**	-	-	**-**
(C) Vertebrates												
Fish bones/scales/fins	1	0.090	**3.0**	2	0.105	**3.6**	7	0.259	**9.6**	1	0.125	**4.0**
(D) Miscellaneous												
Mollusc shells	6	0.545	**18.2**	6	0.316	**10.9**	8	0.296	**11.0**	4	0.500	**16.0**
Marine debris	1	0.090	**3.0**	-	-	**-**	3	0.111	**4.1**	-	-	**-**
Digested materials	10	0.909	**30.4**	18	0.947	**32.7**	19	0.703	**26.0**	6	0.750	**24.0**
Sum of ratios		2.993			2.896			2.701			3.125	

Table 15: Diet analysis of *Balistes capriscus* – Gravimetric method

Size class (TL/cm)	12.0 – 21.9			22.0 – 31.9			32.0 – 41.9			42.0 – 52.0		
	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%
No. of Fish	12			26			28			8		
No. of empty guts	1			7			1			0		
No. of non-empty guts	11			19			27			8		
(A) Zooplankton												
Amphipoda: Hyperiids	-	-	**-**	0.009	-	**-**	0.025	0.001	**-**	-	-	**-**
Copepoda	-	-	**-**	0.005	-	**-**	0.001	-	**-**	-	-	**-**
Eupausiidae	-	-	**-**	0.027	0.001	**-**	-	-	**-**	-	-	**-**
Mysidae	0.007	0.001	**0.1**	-	-	**-**	-	-	**-**	-	-	**-**
Anthomedusa	0.001	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
Jellyfish	-	-	**-**	-	-	**-**	0.098	0.004	**0.1**	-	-	**-**
Fish larvae (Batoid)	-	-	**-**	-	-	**-**	0.005	-	**-**	-	-	**-**
(B) Benthic macroinvertebrates												
Bivalvia	0.002	-	**-**	0.188	0.010	**0.5**	0.396	0.015	**0.4**	-	-	**-**
Decapoda:												
Brachyura (Crabs)	0.697	0.063	**7.3**	0.601	0.032	**1.5**	10.128	0.375	**9.3**	1.196	0.150	**1.4**
Nephropidae (Crayfish/Lobsters)	0.593	0.054	**6.2**	12.630	0.665	**32.0**	12.686	0.470	**11.6**	14.704	1.838	**17.1**
Penaeidae (shrimps)	-	-	**-**	0.211	0.011	**0.5**	5.096	0.189	**4.7**	1.914	0.239	**2.2**
Sepiida:												
Sepia/Flesh of Sepia	-	-	**-**	0.663	0.035	**1.7**	10.677	0.395	**9.8**	49.898	6.237	**58.0**
Nematoda	0.022	0.002	**0.2**	0.078	0.004	**0.2**	0.032	0.001	**-**	0.002	-	**-**
Polychaeta	0.097	0.009	**1.0**	0.065	0.003	**0.1**	-	-	**-**	-	-	**-**
Volutacea: (Cybium)	-	-	**-**	-	-	**-**	0.176	0.007	**0.2**	-	-	**-**
Shell of siphonidae	0.001	-	**-**	-	-	**-**	-	-	**-**	-	-	**-**
(C) Vertebrates												
Fish bones/scales/fins	0.738	0.067	**7.7**	0.616	0.032	**1.5**	2.510	0.093	**2.3**	1.372	0.172	**1.6**
(D) Miscellaneous												
Mollusc shells	0.897	0.082	**9.4**	1.746	0.092	**4.4**	19.857	0.735	**18.2**	16.930	2.116	**19.7**
Marine debris	0.085	0.008	**0.9**	-	-	**-**	4.596	0.170	**4.2**	-	-	**-**
Digested materials	6.397	0.582	**67.1**	22.733	1.196	**57.5**	42.757	1.584	**39.2**	-	-	**-**
Sum of ratios		0.868			2.081			4.039			10.752	

Table 16: Diet analysis of *Balistes punctatus* – Frequency of Occurrence method

Size class (TL/cm)	12.0 – 21.9			22.0 – 31.9			32.0 – 41.9		
	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%
No. of Fish	5			32			4		
No. of empty guts	0			0			0		
No. of non-empty guts	5			32			4		
(A) Zooplankton									
Amphipoda: Hyperiids	1	0.200	**4.5**	2	0.063	**1.8**	-	-	**-**
Mysidae	-	-		2	0.063	**1.8**	1	0.250	**5.3**
Cumacea	1	0.200	**4.5**	1	0.031	**0.9**	-	-	**-**
Lamellibranch larvae	-	-	**-**	2	0.063	**1.8**	1	0.250	**5.3**
Gastropod larvae	-	-	**-**	1	0.031	**0.9**	-	-	**-**
Bivalve larvae	-	-	**-**	1	0.031	**0.9**	-	-	**-**
(B) Benthic macroinvertebrates									
Bivalvia	3	0.600	**13.6**	4	0.125	**3.6**	2	0.500	**10.5**
Decapoda:									
Brachyura (Crabs)	2	0.400	**9.1**	12	0.375	**10.7**	1	0.250	**5.3**
Nephropidae (Crayfish/Lobsters)	3	0.600	**13.6**	7	0.219	**6.3**	2	0.500	**10.5**
Penaeidae (shrimps)	2	0.400	**9.1**	22	0.688	**19.7**	2	0.500	**10.5**
Sepiida:									
Sepia/Flesh of Sepia	-	-	**-**	4	0.125	**3.6**	-	-	**-**
Echinodea (pieces)	1	0.200	**4.5**	13	0.406	**11.6**	2	0.500	**10.5**
(C) Vertebrates									
Fish bones/scales/fins	-	-	**-**	2	0.063	**1.8**	3	0.750	**15.8**
(D) Miscellaneous									
Mollusc shells	2	0.400	**9.1**	5	0.156	**4.5**	1	0.250	**5.3**
Marine debris	1	0.200	**4.5**	8	0.250	**7.1**	-	-	**-**
Sand grains/stones	-	-	**-**	1	0.031	**0.9**	1	0.250	**5.3**
Unidentified	2	0.400	**9.1**	-	-		-	-	**-**
Digested materials	4	0.800	**18.2**	25	0.781	**22.3**	3	0.750	**15.8**
Sum of ratios		4.400			3.501			4.750	

Table 17: Diet analysis of *Balistes punctatus* – Gravimetric method

Size class (TL/cm)	12.0 – 21.9			22.0 – 31.9			32.0 – 41.9		
	No. guts	Ratio	%	No. guts	Ratio	%	No. guts	Ratio	%
No. of Fish	5			32			4		
No. of empty guts	0			0			0		
No. of non-empty guts	5			32			4		
(A) Zooplankton									
Amphipoda: Hyperiids	0.056	0.011	**0.5**	0.038	0.001	**-**	-	-	**-**
Mysidae	-	-	**-**	0.161	0.005	**0.1**	0.106	0.027	**0.3**
Cumacea	0.030	0.006	**0.3**	0.120	0.004	**0.1**	-	-	**-**
Lamellibranch larvae	-	-	**-**	0.039	0.001	**-**	0.025	0.006	**0.1**
Gastropod larvae	-	-	**-**	0.005	0.002	**-**	-	-	**-**
Bivalve larvae	-	-	**-**	0.001	-	**-**	-	-	**-**
(B) Benthic macroinvertebrates									
Bivalvia	0.801	0.160	**7.9**	1.337	0.042	**0.8**	3.501	0.875	**10.4**
Decapoda:									
Brachyura (Crabs)	0.052	0.010	**0.5**	11.006	0.344	**6.2**	0.481	0.120	**1.4**
Nephropidae (Crayfish/Lobsters)	0.556	0.111	**5.5**	2.260	0.071	**1.3**	5.128	1.282	**15.2**
Penaeidae (shrimps)	3.784	0.757	**37.6**	67.690	2.115	**38.2**	0.142	0.036	**0.4**
Sepiida:									
Sepia/Flesh of Sepia	-	-	**-**	6.955	0.217	**3.9**	-	-	**-**
Echinodea (pieces)	0.459	0.092	**4.6**	28.355	0.886	**16.0**	3.327	0.832	**9.9**
(C) Vertebrates									
Fish bones/scales/fins	-	-	**-**	0.041	0.001	**-**	8.477	2.119	**25.2**
(D) Miscellaneous									
Mollusc shells	0.002	-	**-**	2.978	0.093	**1.7**	0.001	-	**-**
Marine debris	0.261	0.052	**2.6**	13.149	0.411	**7.4**	-	-	**-**
Sand grains/stones	-	-	**-**	0.036	0.001	**-**	0.132	0.033	**0.4**
Unidentified	0.049	0.010	**0.5**	-	-	**-**	-	-	**-**
Digested materials	4.020	0.804	**39.9**	42.759	1.336	**24.2**	12.328	3.082	**36.6**
Sum of ratios		2.013			5.530			8.412	

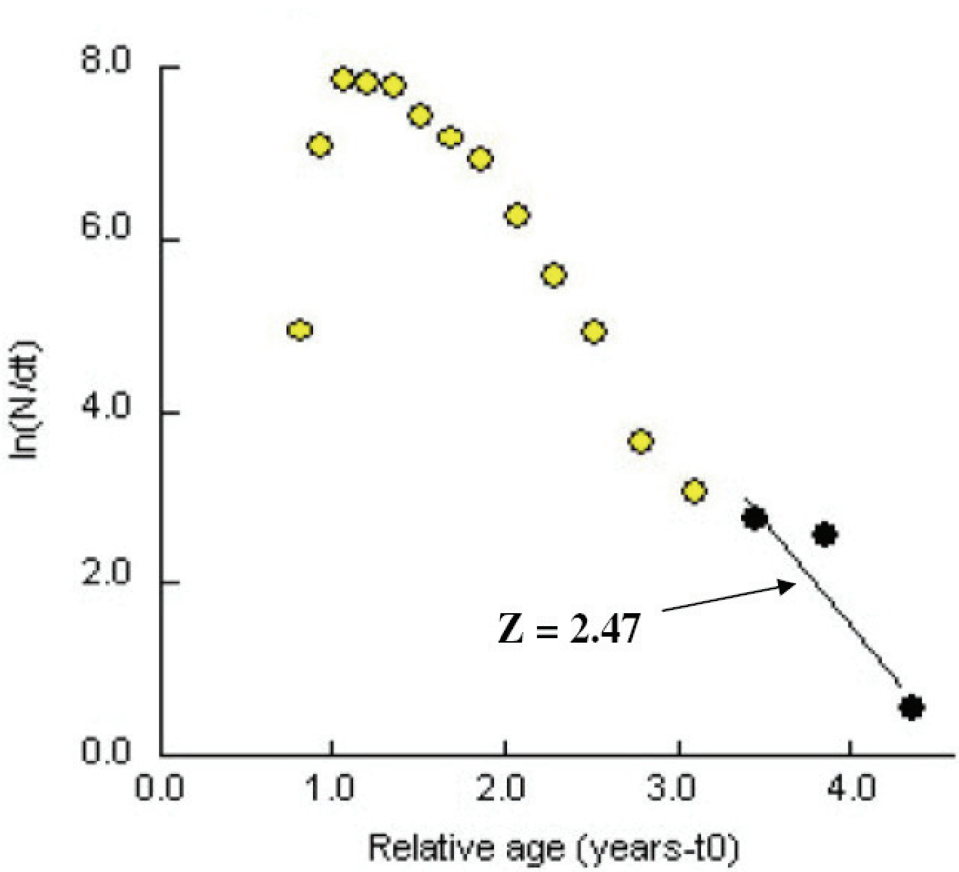


Fig. 32: Length-converted catch curve of *Balistes capriscus* for estimation of *Z* in 1980. Length-frequency data were obtained from midlength-frequency plots of *B. capriscus* in Ofori-Danson 1981. L_∞ = 40.8 cm; K = 0.43yr^{-1}; M = 0.81 (using Pauly's M equation); E = 0.67 as at 1980