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Prof Nico Smit

Fishing for Science: An ecological journey

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Fishing for Science: An ecological journey

Nico J Smit

Unit for Environmental Sciences and Management & School of Biological Sciences, Potchefstroom Campus, North West University, Private Bag X6001, Potchefstroom, 2520, South Africa.

1. Introduction

African freshwater fish are an important natural source of protein and provide 21% of the total protein intake on the continent (Revenga et al. 1998). Locals are dependent on inland fish as either a source of food or a means of income; for this reason fish have great significance in the life of mankind, especially for those living in poverty within the immediate vicinity of fish populations. Fish not only plays a major role as a protein source for local rural communities, but also promotes the tourism industry in terms of recreational and sport game fishing. However, fish also plays a very vital role in the ecology of an aquatic system and thus form an important theme for scientific research. This is specifically true when the fish itself is studied as a mini ecosystem for other animals (symbionts) as well as when fish are used as an indicator of aquatic ecosystem health.

The term ecology was coined by Ernest Haeckel in 1869 who stated that ecology is the study of the interactions between organisms and their environment. Since the time of Haeckel many different definitions for ecology has been proposed, but in essence the basic concepts of interactions between organisms as well as their interaction with the environment they live in, were always included in these definitions. The aims of this paper is to firstly take the reader on an ecological journey of how fish can serve, not only as a food source, but also as an ecological system in its own right and secondly to show the important role fish play in the function and structure of an aquatic system and how it can be used to determine the health of that system. This journey can be broken down into three different parts, i. the interactions between organisms; ii. interactions between organisms and the environment and iii. interactions between organisms and human altered environments. The latter is included, because one cannot study the environment without including anthropogenic impacts.

2. Fish as an ecosystem: interactions between organisms

One of the most interesting interactions between organisms is the symbiotic relationship between two organisms. This is basically the living together of organisms with one having some sort of influence on the life of the other. One of these symbiotic relationships is called parasitism, which implies that one organism (the parasite) live in or on another organism (the host). In this relationship the parasite usually cause some sort of harm to the host. Fish are no exception; they can act as both parasite and host. For the purpose of this section of the paper the focus will be on fish as host. Fish seems to be a perfect host for quite an amazing diversity of parasites. In a single fish the potential exist to find from single cell Protozoa parasites through all the different phyla of parasitic invertebrates up to Crustacea (Woo, 2006). One of the most intriguing of these fish parasitic groups belongs to the crustacean order Isopoda. Fish parasitic isopods are found in two Families, the Gnathiidae and Cymothoidae. Members of the Gnathiidae are only parasitic in their larval stages with the adults being free living benthic organisms (Smit & Davies, 2004). The Cymothoidae, on the other hand, are permanent parasites of fish and can attached to the body survey, fins, gills or even the tongue of fishes. Both these groups are mainly marine organisms with a very few records from brackish and freshwater environments. Both groups also have very interesting and complex life strategies which make them intriguing to study.

Up to the twenty-first century only 4 species of Gnathiidae were known from South Africa, and almost nothing about their ecology and biology (Smit & Van As, 2000). These species were *Gnathia africana* Barnard 1914, *G. spongicola* Barnard, 1914, *Gnathia disjuncta* and *Caecognathia cryptopais* (Barnard 1925) (see Smit et al. 2000). The gnathiid larvae are perfectly built to be parasites of fished with large compound eyes (Fig 1A) to find the host and piercing - sucking mouthparts to feed on fish lymph and blood (Smit et al., 2003). They have 3 larval stages and then the final stage, known as praniza 3, moult into an adult male or female. The moulting process from a praniza 3 to a male is quite extraordinary, because they don't just shed their skin, they actually grow a complete new head (cephalosome) which forms a magnificent feature that distinguishes this group of organisms (Fig. 1B). The adult female has eggs that get internally fertilized by the male. After fertilization the eggs are transferred from the ovaries to a marsupium, where the female keep the eggs and developing larvae. In the case of *G. africana* the larvae start moving around in the marsupium at about 3 weeks post fertilization (Smit et al., 2003). This movement signals that they are ready to leave the female to find a fish to feed on and continue their life cycle.

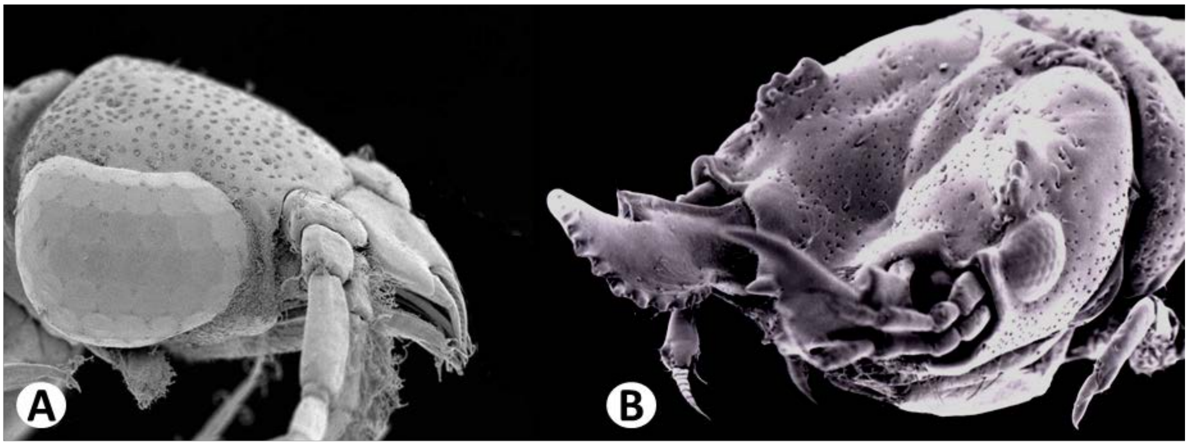

Figure 1: A. Typical head (cephalosome) of a gnathiid larvae with large eyes and piercing-sucking mouthparts. B. Robust head (cephalosome) of a male *Gnatia africana* with distinct mandibles and eyes.

Work on gnathiid fish parasites in South Africa over the past 13 years has led to the discovery of 4 more new gnathiid species, thus doubling the number of known species from this region. These species include *Gnathia nkulu* Smit & Van As, 2000; *Gnathia pantherina* Smit & Basson, 2002; a new genus of gnathiid, *Afrignathia multicavea* Hadfield & Smit, 2008 and *Gnathia pilosus* Hadfield, Smit & Avenant-Oldewage, 2008. *Gnathia pantherina* is a very interesting species, as the larvae parasites sharks. The description of *G. pantherina* from South African sharks was the first ever description of this parasite from a shark. Research on gnathiid fish parasites in South Africa has recently been extended to the Great Barrier Reef, Australia were we have described 5 new species as well as to the Caribbean where *Gnathia marley* Farquharson, Smit & Sikkel, 2012 was added to the new species list. The latter gnathiid was named for Bob Marley and the publication of that species caused quite a media hype world-wide

As previously mentioned, fish also have protozoan parasites. This is also the case in South Africa and specifically true for marine species that harbour fish blood parasites. The most common marine fish blood parasite in South Africa is *Haemogregarina bigemina* Laveran & Mesnil, 1901 from intertidal fishes such as the super klipfish, *Clinus superciliosus*. This blood parasite occurs in a variety of fishes in widely separated geographical locations, which includes Europe, Britain, the Caribbean, New Zealand and Australia. It was first reported from South Africa in 1999 (Smit & Davies, 1999), and this record of it was the first record of a marine fish blood parasite in South Africa since the description of *Desseria fragilis* by H.O. Fantham in 1930 (Smit et al., 2003). The third species to be reported from South Africa was *Haemogregarina koppiensis* (Smit & Davies 2001) from the Evileye Pufferfish, *Amblyrhynchotes honkenii*. This was followed a few years later by the description of *Desseria zei* Smit & Davies, 2006 from the deep sea Cape Dory, *Zeus capensis*, and *Haemogregarina curvata* Hayes, Smit, Seddon, Wetheim & Davies 2006, infecting the blood of various intertidal fishes along the South Coast of South Africa. Recently we also decribed the first fish blood parasite from the East Coast as *Haemogregarina kunegemina* Ferreira, Smit & Davies, 2012. This parasite was discovered in the blood of the intertidal blennie, the Horned rockskippers, *Antennablennius bifilum*.

The question thus arises, what does blood parasites, such as these fish haemogregarines and blood sucking parasites (gnathiids) have in common. First of all they use a fish as their ecosystem, but secondly they also interact with each other in this unique environment. The idea that gnathiid isopods can transmit blood parasites between fishes was already postulated in the 1970's by Davies & Johnston (176). However, these authors could never found conclusive evidence to support their hypothesis. The work in South Africa on gnathiid isopods and fish blood parasites lead to the opportunity to further study the idea of gnathiids being vectors of fish blood parasites. Using the intertidal fish, *C. superciliosus* infected with the blood parasite, *H. bigemina*, and the gnathiid, *G. africana* as experimental models, Davies and Smit (2001) discovered that the South African gnathiids can also transmit fish blood parasites. This was a very significant discovery as up to that moment it was generally accepted that only a leech can transmit blood parasites within an aquatic environment. Since the publication of Davies & Smit (2001) this mode of blood parasite transmission has internationally been accepted and all the recent general parasitology textbooks and specialists books on fish parasitology report that gnathiid isopods can act as a vector of fish blood parasites and plays an important role in the transmission of blood parasites (Woo, 2006). This incredible discovery in South Africa were further supported by recent work in Australia that also showed that an Australian gnathiid, *Gnathia aureamaculosa* Ferreira, Smit, Grutter & Davies 2009, can transmit the blood parasite, *Haemogregarina balistapi*, Smit, Grutter, Adlard & Davies 2006, between triggerfish, *Rhinecanthus aculeatus* (see the paper by Curtis et al. 2013). This confirms that what was discovered in South Africa can also occur in a complete different environment between different fish, different blood parasites and different gnathiid species.

The second family of parasitic isopods mentioned above, was the Cymothoidae. These are just as amazing parasites of fishes as gnathiid isopods and because of their large size (up to 7cm long), easily catches the eye of fishermen and fish mongers. Although cymothoids can attached anywhere on a fish's body, the group that received the most public attention to date is those that sit in the fishes mouth and attached to the tongue (Fig. 2A). How this animal gets there is that it crawls through the gills of the fish into the mouth and then sits on the tongue of the fish. After it attaches to the tongue it starts feeding on host blood and tissue and when it reaches its full adult size the tongue has completely disappeared. To date no one is sure whether the parasite actually feeds on the tongue of the host or whether the tongue just disintegrate due its blood flow being cut off by the hooks (dactylus of the pereopods) the isopod uses for attaching to the tongue. After the disappearance of the fish's tongue an amazing thing happens, the isopod that lives in the mouth of the fish starts to function as the tongue of the fish. This is the only known case in the world of one animal replacing a functional body part of another animal and then function as that body part. In South Africa we recently discovered a new species of this tongue replacement isopod and named it *Cymothoa sodwana* Hadfield, Bruce & Smit, 2013 (Fig. 2B). We discovered it in Sodawna Bay in the mouth of the Large-spotted Pompano, *Trachinotus botla*. This was the first description of a new species of tongue replacement isopods from South Africa in more than 100 years.

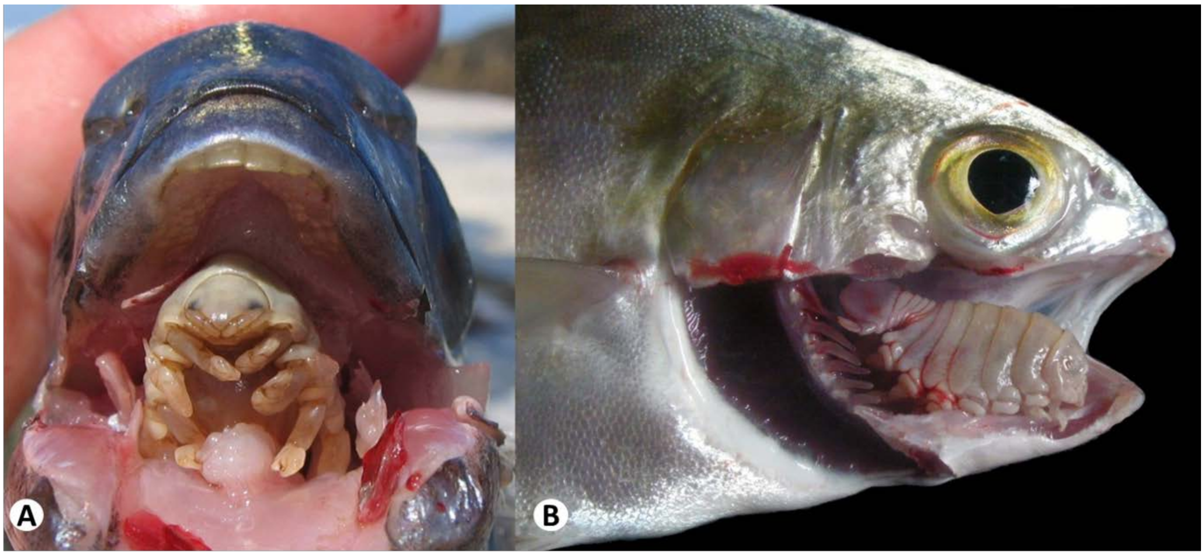

Figure 2: A. *Ceratothoa* sp. in the mouth of a Black Tail, *Diplodus capensis* caught in Tsitsikama National Park. B. *Cymothoa sodwana* in the mouth of a Large-spotted Pompano, Trachinotus botla caught at Sodwana Bay.

3. Fish as an indicator of environmental health: the interaction between organisms and the environment

The focus of this section of the paper will be on the tigerfish, *Hydrocynus vittatus* (Fig. 3). Tigerfish (*H. vittatus*) are widely distributed in the North Eastern region of South Africa and are recognised as a flagship species, thus a species of fish that is easily identified by the public and widely used by ecosystem managers to relate important ecosystem related information to the public (Smit et al. 2009). The tigerfish, is one of the most important freshwater fish species in Southern Africa because of its economic and livelihood value. This species is actively targeted and utilised by various angling and subsistence fishing communities throughout this part of the country, and is also used as indicator species by resource and water quality managers. Tigerfish therefore has a high ecological, economic and social value to South Africans. Although valuable, very little is known about the biology and environmental requirements of this charismatic species. As a result of its ecological and economic importance the tigerfish has been the focal point of five different research projects undertaken by my research group over the past 10 years.

Figure 3: The tigerfish, *Hydrocynus vittatus.*

Despite the importance of tigerfish, few aging studies are available for this species. According to Griffith (1975) the management of this species has been hindered by this lack of knowledge on its age structure. The first work we thus did on tigerfish was to determine the correct structure to use for aging and then also to determine the age of the fish itself. This research done in tigerfish from the Okavango Delta resulted in a paper by Gerber et al. (2009) who compared the scales, and whole and sectioned lapillus otoliths to determine the best method for use in the ageing of this species in order to ensure ageing accuracy. The most appropriate method for ageing *H. vittatus* was found to be the sectioned lapillus otoliths. The ageing study by Gerber et al. (2009) showed that male tigerfish did not disappear from populations at a young age, as previously thought and in fact lived for 20 years, while females lived for up to 16 years. This was an amazing discovery as previous studies suggested that tigerfish only live up to 12 years. The fact that they actually live much longer than expected has a significant impact on their ecology and their conservation.

The genetic make-up of any species provides valuable information on its interaction with the environment as well as the long term survival of that specific species. The higher the genetic diversity of a population, the higher the probability of survival when its environment changes. In order to understand the genetic variability of tigerfish populations we studied the quantity and pattern of genetic variation in tigerfish of the Okavango Delta (Soekoe et al., 2009). Soekoe et al. (2009) found that despite the original hypothesis that Okavango Delta tigerfish will have the highest diversity of all the different tigerfish populations, they actually showed the lowest heterozygosity. These authors stated that a possible cause of this low variation might be due to the founder effect instigated when the Okavango and Zambezi rivers became separated. Another possible explanation could be that the Okavango is a more stable system and therefore large variation might not be required by individuals for survival. These results further indicated that due to this low genetic diversity the tigerfish in the Okavango might not be able to survive large scale environmental changes, especially those of an anthropogenic nature.

One of these anthropogenic induced stressors to fish, and especially popular angling species, such as the tigerfish, is the physiological stress caused by angling. Although the sport-fishing industry encourages anglers to practice catch-and-release angling, no studies have been done on the effect this practice may have on tigerfish or any other freshwater sport-fishing species in Africa. The effect of catch-and-release angling on tigerfish is of utmost importance as the ultimate success of this type of angling depends on the survival of the fish by minimising injury and mortality. Following high-intensity anaerobic exercise, various studies have shown that once captured the blood lactate levels in fish are elevated and may possibly be associated with delayed mortality. Due to these concerns Smit et al. (2009) studied the use of blood lactate as a biomarker for angling-induced metabolic stress in tigerfish and examined the relationship between angling time and blood lactate levels. These authors analysed the landing time, handling time, body mass, total length and blood from 66 anaesthetised fish. A strong, positive correlation ($r^2 = 0.607$) was seen between the landing time and body mass of landed fish as well as significant elevations in blood lactate levels subsequent to angling, regardless of angling time. These results led the authors to conclude that longer angling time significantly increases physiological stress, in turn possibly impacting on the breeding success and mortality of tigerfish. If angled fish have the opportunity to remove the lactate from the blood, then their chance of survival will increase dramatically, however, to remove the lactate from the blood the fish needs oxygen. Unfortunately, in most cases anglers remove the fish from the water just after capture for photos, weighing and measuring. In doing this the fish can't breathe (thus get oxygen). This is similar to when Usain Bolt runs the 200m and the moment he crosses the finish line, you catch him and put his head in a bucket of water. Based on this angling stress work we have showed that the only way how catching and release can be viable conservation strategy, is when you do it correctly, thus shorten angling times by using heavier angling gear, keep the time out of the water as short as possible and keep the fish in the water for recovery before release.

4. Fish as an affective bio monitoring tool: interactions between organisms and human altered environments

There are a number of advantages in using fish as a bio monitoring tool. Fish are relatively easy to identify and are present in most water bodies. Fish from different trophic levels can be present in a fish community, which allows for studying the anthropogenic impacts on the whole food web. The long term conditions and effects can also be determined due to the long lifespan of fish (up to 20 years for tigerfish, see above). In a recent completed project Smit et al. (2013) studied the suitability of tigerfish as indicator species for water quantity and quality in the Luvuvhu and Olifants River in Kruger National Park (KNP). Tigerfish are one of the few indigenous top predator fish species of South Africa and it is well documented that top predators bio-magnify pollutants and the risk that these pollutants pose are greater to them than to the lower trophic levels.

The results from this KNP tigerfish study indicated that the concentrations of the metals Cd, Cu, Mn and Zn in tigerfish tissue from both rivers have decreased from 2009 to 2011, whereas the rest of the metals studied have remained constant over the three-year sampling period. There were also no significant temporal changes in bioaccumulation of individual metals. With the exception of Al, all metals were lower in tigerfish from the Luvuvhu River when compared to the Olifants River's bioaccumulation results. One of the most significant results from this study was the discovery very high levels of the pesticide DDT in the muscle tissue of the tigerfish from the Luvuvhu River tigerfish. In fact the ΣDDTs measured during the low flow survey (August) of 2010 were the highest levels recorded in any fish from South African freshwater systems. The high levels can be attributed to the application of DDT for malaria vector control in the upper catchment of the Luvuvhu River. The low DDE:DDT ratio indicated that the DDT exposure is a mixture of recent DDT application and historical levels. The wide-scale application of organochloride pesticides (OCPs) in the catchment of the study area was also evident from the high levels of chlordane, lindane, Endrin and Aldrin present in the tigerfish. It was, however, interesting to note that this study showed that although there were measurable levels of Dieldrin in sediment samples, this highly persistent and toxic pesticide did not bioaccumulate in tigerfish muscle. This study thus further confirmed the very important role fish can play in the study of the effect of anthropogenic activities on an aquatic ecosystem and specifically if a top predator species, such as the tigerfish, is used as bio-indicator species.

5. Conclusion

This paper set out to show firstly how fish can serve, not only as a food source, but also as an ecological system in its own right and secondly to show the important role fish play in the function and structure of an aquatic system and how it can be used to determine the health of that system. This was done through the use of examples from the results of the past 15 years of dedicated research by the author and his research team on various aspects of the ecology of fishes. These results clearly indicated the value of this type of research. It further showed that scientific studies are vitally important to gain an understanding of all aspects of the biology of various fish species and their symbionts, in order to develop management plans for the protection of these aquatic habitats and species therein. It is thus crucial that we keep on fishing for science.

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