A biological assessment of the Cape knifejaw (*Oplegnathus conwayi*) an endemic South African teleost

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Abstract

The South African spearfishery forms a small component of South Africa's complex coastal fishery. Although the smallest, this fishery sector has the largest proportion of data deficient species, and as a consequence is poorly managed. *Oplegnathus conwayi* (Cape knifejaw) is an example of one of these species for which there is very little and outdated biological and ecological data. This species is among the top target species by recreational spearfishers in South Africa. This thesis aimed to improve our socio-ecological knowledge of the South African spearfishery through the collection of biological and Fishers' Ecological Knowledge (FEK) information on *Oplegnathus conwayi,* and human dimension information on the South African spearfishery.

Monthly biological samples were collected through routine sampling (spearfishing) and augmented by recreational spearfishers. A total of 254 fish were collected from the warm-temperate coastal zone (East London – Cape Agulhas), 28 from the sub-tropical zone (Durban – East London) and 23 from the cool-temperate zone (Cape Agulhas – Cape Point). The results indicated that *Oplegnathus conwayi* is a slow-growing species, with a maximum recorded age of 27 years. The population sex ratio was skewed, with males dominant in the population (1M:0.6F). The length- and age-frequency distributions were, however, similar for both sexes. No significant differences were observed between male and female growth (LRT, $p > 0.05$), with the overall population growth curve being best described as $L(t) = 697.15(1-e^{-0.06(t-6.30)})$. Males matured at a slightly larger size than females, however, no significant differences were observed (LRT, $p > 0.05$). The length- and age- at-50% maturity was 330 mm (FL) and 5.73 years for the full population, respectively. Histological analyses showed that *Oplegnathus conwayi* are asynchronous spawners with a gonochoristic reproductive style. Macroscopic staging and gonadosomatic index results indicated a protracted spawning season for *Oplegnathus conwayi,* with a peak in spring.

A survey was designed and disseminated to collect FEK on the biology and population status of *Oplegnathus conwayi* and human dimension information on South Africa's spearfishery. A total of 103 survey responses were received, of which 94 were regarded as specialised (spearfishers who had greater experience, skill and avidity, and maintained spearfishing as an important component of their lifestyle) spearfishers. Based on the responses of the specialist spearfishers, the top four main species caught by spearfishers from this survey were *Seriola lalandi* (13.9%), *Pachymetopon grande* (11.7%), *Oplegnathus conwayi* (11.4%)

and *Sparodon durbanensis* (11%), and the majority of respondents indicated that there had been no changes in abundance, size and catches of these species in the years that they had been spearfishing. Respondents indicated that *Oplegnathus conwayi* are most commonly targeted in the Eastern Cape and are found at depths of up to 40 m. Respondents also indicated that there may be a seasonal onshore (Summer/Winter) and offshore (Summer/Winter) migration with year-round spawning and a peak in November, December and January.

The incorporation of spearfishers into the data collection, both through the collection of specimens and their FEK, was beneficial to this study. Besides providing samples from a broader geographical range than the primary collection area, the collaboration with spearfishers has promoted the inclusion of this group into the management system. The findings of this study also suggest that FEK data can be more reliable if the concept of recreational specialisation is incorporated into data collection.

While the FEK suggested that the population was stable, a stock assessment is necessary to fully understand the population status and implement management strategies. Nevertheless, the key life history characteristics (slow growth and late maturation) observed in this study are characteristic of species that is vulnerable to overexploitation, and thus the precautionary approach should be applied. The reproductive information collected in this study has provided information for the implementation of an appropriate size limit regulation for *Oplegnathus conwayi*. Here, a minimum size limit of 400 mm TL, which corresponds approximately with the length-at-50% maturity of 330 mm FL, would be appropriate to allow fish to mature and spawn, and reduce the likelihood of recruitment overfishing. Reduction in the bag limit from five to two fish per person per day may also be appropriate as a precautionary measure until a stock assessment has been completed. Finally, the incorporation of stakeholder into biological collection and the use of FEK may be a useful approach for other data deficient species and in countries with limited resources for ecological research.

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CHAPTER 1

Introduction

Coastal fisheries are among the most complex fishery systems worldwide, with extremely high numbers of users (Stewart et al 2010, FAO 2018, Arlinghaus et al 2019). The fishery sectors in these systems are broad, and include subsistence (who rely solely on the coast for food and livelihood), recreational (who use the coast for recreational pleasure, including non-consumptive and consumptive use) and commercial (who make revenue from coastal resources) fishers (Stewart et al 2010, FAO 2018, Arlinghaus et al 2019). Each of these sectors have their own interested and affected stakeholders, such as the local and international distributors, boat and tackle industry and tourism sector (Stewart et al 2010, FAO 2018). The large proportion of participants and high variability within the users, results in a high diversity of fish being targeted by all sectors. The complexity of the resource, its users and stakeholders, make coastal fisheries challenging to manage.

Traditionally, coastal fisheries have been managed through a mixture of effort control and single-species fisheries regulations. However, these traditional strategies have often failed, partly due to the inherent complexity of coastal fisheries (Pitcher 2001, Mahon et al 2008). More recently, and in response to the shift to an ecosystem approach to fisheries management (Caddy and Cochrane 2001, FAO 2003), an attempt has been made to embrace the complexity of coastal fisheries and this can be done by viewing these as complex socio-ecological systems (SES).

Social-ecological systems have been defined as "linked systems of people and nature, emphasising that humans must be seen as a part of, and not apart from, nature" (Berkes and Folke 1998). Their management requires not only an understanding of all drivers and influences, but also how they work interchangeably and influence each other (Ostrom 2009, Butler 2019). Ostrom (2007, 2009) developed a general SES framework that can be adapted to various fields and systems, which enables scientists to predict interactions, outcomes and drivers that may influence these systems. Ostrom's framework includes four core subsystems and, in the context of coastal fisheries, the resource systems (e.g. the recreational fishery), resource units (e.g. fish species), governance systems (e.g. fisheries regulations) and users (e.g. fishers). This framework has been used across various scientific fields, with each application manipulating and adapting it accordingly (McGinnis and Ostrom 2014). The adoption of a framework that incorporates the ecological and human dimension to complex systems, like that of coastal fisheries, would undoubtedly be beneficial for the successful management of these systems. These frameworks allow for a holistic understanding of the systems, which provides fisheries managers with the best possible information for decision-making.

South Africa is a developing country with one of the most complex coastal fisheries systems in the world (Potts et al 2020a), including five linefishery subsectors (boat-based recreational, commercial, small-scale and shore-based recreational, and small-scale sectors) and one spearfishing sector (Figure 1.1). These sectors all compete for similar marine resources with significant resource overlaps (see Figure 1.1). The overlapping and interlinked nature of this system invokes conflict among the various sectors, and makes it difficult to maintain a resilient, equitable system.

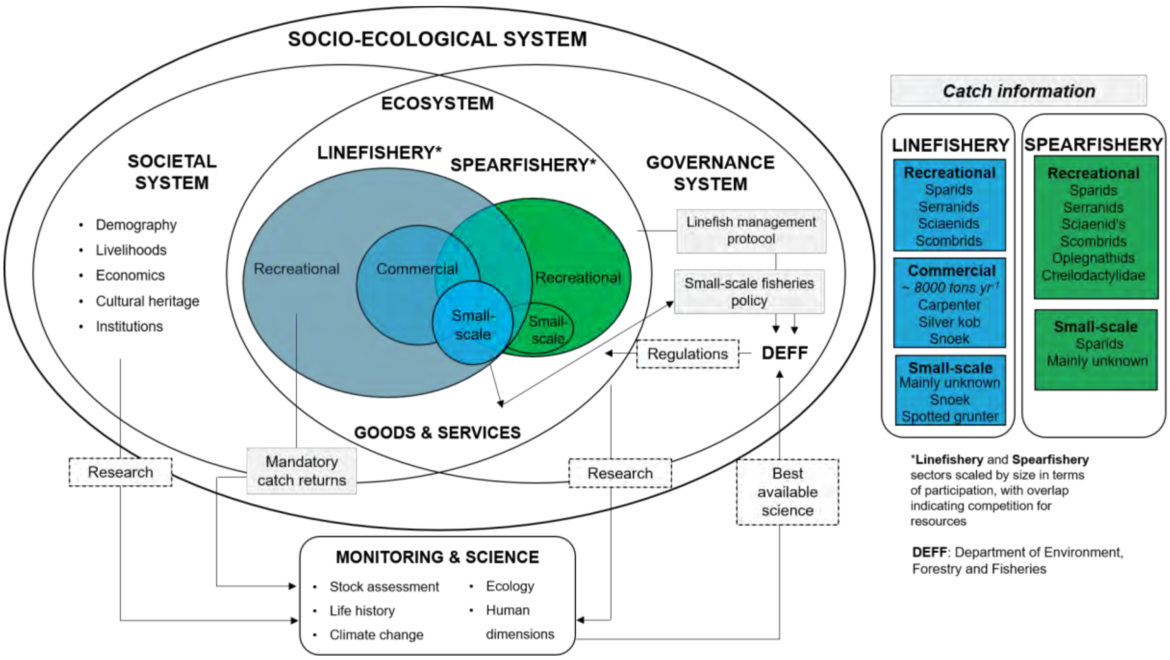

Figure 1.1: South Africa's recreational social-ecological system adapted from Potts et al (2020a), incorporating South Africa's spearfishery. The fishery sectors are scaled according to the size of participation within the fishery, with the overlap indicating competition for resources.

When divided by gear, participation in the coastal fishery is dominated by the linefishery and this sector has by far the greatest impact on the resources. There has been considerable research on the target species in the linefishery component, particularly on those captured by the commercial sector (Potts et al 2020a). Indeed, the life history of the majority of species targeted by the linefishery have been described (Mann 2013). Nevertheless, despite this, the management of these species has been poor with stock declines observed for many species (Potts et al 2020a).

The South African spearfishery is a small sector of South Africa's coastal fisheries, with an estimated 33 616 participants (Saayman et al 2017). This small size has been attributed to the physicality, mental strength and risks involved in spearfishing (van Rooyen 2012). Species primarily targeted in this fishery are region-specific, however, some of the main target species include *Lichia amia*, *Seriola lalandi*, *Sparodon durbanensis*, *Pachymetopon grande*, *Umbrina robinsoni* and the *Oplegnathid spp* (Mann et al 1997, Mann 2013). Five target species are almost exclusively harvested by spearfishers. They include *Oplegnathus conwayi, Oplegnathus robinsoni, Chirodactylus jessicalenorum, Chirodactylus grandis,* and *Parascorpis typus* (Mann et al 1997, Mann 2013). Despite its small size, the spearfishery can have a considerable impact on fish stocks due to its selective nature, with many spearfishers both internationally and in South Africa actively targeting trophy specimens (largest and heaviest individuals) (Russel 1977, Coll et al 2004, Lloret et al 2008) which are extremely valuable for their reproductive potential (Longhurst 2002, Berkeley et al 2004a, Palumbi 2004, Scott et al 2006). This potential impact has not been fully recognised by the National Government's management authority and up to now, few resources have been dedicated to the management of this sector. This is not unusual as there is a general lack of recognition and limited dedicated resources for this sector globally (Giglio et al 2020).

There is a general lack of information on the characteristics of recreational spearfisheries and the ecology of their target species and consequently the management of them is often poor (Giglio et al 2020). This is particularly concerning in a country such as South Africa, where population declines in the targeted fish populations would result in shifts in targeted effort towards species that are traditionally captured in the linefishery sector (Figure 1.1). This would place strain on the coastal fishery SES, particularly at a time when the government is attempting to implement the small-scale fisheries policy, which will result in the addition of more fishers and increased fishing pressure (Potts et al 2020a).

One of the key components of successfully understanding a SES is the collection of biological and ecological data. Traditionally, this was the only form of data collected and fisheries managers inferred management measures based only on this data (King and McFarlane 2003). The collection of this data is still imperative and still used in integrated management (Garcia et al 2003). However, this is a challenge for the recreational spearfishery mainly due to the difficulty and cost associated with the collection of specimens. Unlike the commercial sector, where fish are landed in official landing sites, spearfishers are broadly dispersed, highly mobile and their fishing effort is highly dependent on sea conditions and, is thus unpredictable. This makes the design of dedicated biological sampling programmes a challenge, even in the developed world. In developing countries, the funding required to conduct this research is less likely to be available. For example, South Africa has a recognised recreational sector (including the spearfishery) in policy, and the licensing system ensures that there should be funding for species-specific research. However, the policy's implementation has been poor, and funding has not recently been made available for biological data collection (Potts et al 2020a).

One approach to improve the efficacy and cost of biological data collection is through citizen science. The term "citizen science" has been adapted and used in various ways, but is generally accepted as including the public in scientific projects (Kobori et al 2016). Citizen science activities can be broad, but in the context of fisheries, may include participating in tagging programmes (Dunlop et al 2013), the collection of specimens for biological sampling or, for individuals with extensive knowledge, compiling of reports on the status of fish stocks (Fairclough et al 2014). The incorporation of the public into biological sampling programs is growing. The remarkable success of Australia's citizen science programme, "*Send us your Skeletons*" (SUYS) (Fairclough et al 2014), highlights the value of this kind of research. During this programme, recreational fishers were asked to donate the skeletons of key research species to scientists to extract biological data and produce important life-history information. Besides the collection of scientific data, the development of citizen science programmes has additional benefits. For example, involving fishers in scientific projects promotes improved communication among fishers, scientists and managers (Dedual et al 2013) which, in turn, results in a better understanding of the needs and wants of each party and optimal management measures being implemented (Dedual et al 2013). This involvement gives the fishers incentive to buy into the idea and often results in better compliance (Dedual et al 2013).

The incorporation of citizens into science in South Africa started as early as 1938, with the collection of the coelacanth and anecdotal evidence of J.L.B Smith using citizen scientists to help collect specimens (Potts et al, in review). More recently, engagements such as the ABALOBI app, Echinomap, South African Elasmobranch Monitoring (ELMO), Fishtory and Catch Report have all added valuable data for training and educational workshops (Potts et al, in review). Undoubtedly, one of the most successful citizen science projects in South Africa is the Oceanographic Research Institute – Cooperative Fish Tagging Project (ORI-CFTP). This project was first developed in 1984 with the aim of collecting fish movement data through recreational fishers. This project has over 6000 registered participants and has produced over 80 scientific publications (Potts et al, in review). The WWF recently initiated the "Fish for Life" project to engage with the general and recreational angling public to solve resource problems, such as a lack of historical catch, effort and fish size data (fishforlife.co.za). Other than the ORI-CFTP, all of the above citizen science projects are relatively new and have not yet built sufficient data to make valuable inputs into the management of South Africa's recreational fishery (Potts et al, in review). However, the large increase in new projects is a positive sign for incorporating citizen science into South Africa's recreational fishery in the future.

Besides understanding the ecological component of the SES, the collection of information on the social system is extremely important. However, this component has traditionally been neglected, even though researchers have called for the integration of the social system from as early as the 1970s (Hunt et al 2013). Fortunately, fisheries scientists and biologists are beginning to embrace the incorporation of human dimensions into their research (Hunt et al 2013). Indeed, several global studies (eg. Beaudreau and Levin 2014, Bradford et al. 2019, Hewett 2019) have successfully integrated Fishers' Ecological Knowledge (FEK) into studies on the biology of fishery species, which incorporates local fishers' knowledge. Understanding fishers' thoughts and actions in relation to fish, fishing and governance equips fisheries managers with an improved understanding of how to better manage the resource (Huntington et al 2004, Gilchrist et al 2005, Hunt et al 2013). If management measures are made without considering the fisher's thoughts and actions, compliance is difficult to achieve (Solomon et al 2015). It is therefore unsurprising that the incorporation of human dimensions into fisheries research and SES thinking has become important for addressing non-compliance (Nielsen and Mathiesen 2003, Arias and Sutton 2013, Thomas et al 2016).

Despite increases in human dimension research in fisheries, few studies have focussed on spearfisheries. Assis et al (2018), however, assessed various aspects of spearfishers human dimensions in Portugal. Respondents indicated that spearfishing promotes physical well-being, outdoor enjoyment and an escape from life. They also identified that spearfishers thought that the current regulations were inappropriate and unfair. Information such as this allows fisheries managers to reassess the specific laws in place, and how these could be adapted to benefit both parties.

In cases where there is little fisheries and biological data, the social system may be extremely valuable. The incorporation of FEK has become a popular method to obtain missing fishery and biological information and has also improved scientists' understanding of the resource from the fisher's perspective. Fishers' Ecological Knowledge has added significant value to understanding complex SES worldwide, improving fisheries management and reducing the gap between resource users and scientists (Murray et al 2011, Hind 2015). The use of FEK data has also become particularly beneficial when collecting preliminary biological and ecological data on species that are difficult to sample, or in countries with limited research budgets, and allows precautionary management measures to be implemented (Bradford et al 2019). For example, Silvano et al (2006) used FEK to collect migration and reproductive data on coastal fishes of Brazil.

Besides providing life history information, FEK has also been used to provide information on the stock status of various fishery species (Paterson et al 2010). In the case of spearfisheries, Bradford et al (2019) used FEK to understand the changes in the stock status of spearfishers' target species on the Great Barrier Reef. Similarly, Pita et al (2020) used spearfisher and angler FEK to assess species in the Galicia marine ecosystem in Spain. While the use of FEK data in South Africa has increased over the years, with multiple studies focusing on South African recreational fishery, and some on specific species (Brouwer et al 1997, Mann et al 1997, van Zyl 2011, Dunlop and Mann 2012, Hewett 2019), no studies have focused on spearfisher FEK in South Africa, with the exception of Mann et al (1997).

Currently, the South African spearfishery is severely data deficient. The last assessment conducted specifically on this fishery was more than two decades ago by Mann et al (1997), who investigated the participation and management of the fishery. The study concluded that spearfishers showed a positive response towards linefish management measures, yet compliance, in general, was low. The only biological study, to date, explicitly conducted on a species exclusively targeted by spearfishers, was that of Chater et al (1995), who undertook an initial preliminary assessment on two *Oplegnathid* species. More recently, however, Lloyd et al (2012) assessed the effects of ocean warming on the abundance and diversity of species targeted by spearfishers off the Kwa-Zulu Natal coast, South Africa. The data used in this study was one of those authors' spearfishing catches, with additional catch records from other spearfishers over a 19-year period. Lloyd et al (2012) observed a poleward shift in fish distribution, with an increase in the distribution of tropical fishes and a squeezing of temperate fishes, over the 19-year period. Given the paucity of available data, South Africa's spearfishery, much like that observed worldwide, is in dire need of scientific information.

This thesis aimed to improve the socio-ecological knowledge of the South African spearfishery through the collection of biological information on *Oplegnathus conwayi* (Cape knifejaw) and human dimension information on the South African spearfishery. This information will be used to propose improvements on the current species-specific regulations for *O. conwayi* and the management of the spearfishery.

Thesis Outline

To achieve the aim of this thesis, the thesis has been divided into four chapters. The current chapter introduces the thesis and the South African spearfishery. Chapter 2 is a concise description of the study site and study species. This is followed by two data-orientated chapters. The first (Chapter 3) uses traditional field sampling techniques and citizen science to collect samples to provide a first description of the life history of *O. conwayi*. The second data chapter (Chapter 4) uses a survey to collect FEK on *O. conwayi* and to characterise aspects of the social dimension of the South African spearfishery. The final chapter (Chapter 5) uses a socio-ecological approach to discuss the previous chapters' findings and makes recommendations for improved management of *O. conwayi* and the South African spearfishery in general. The thesis concludes by discussing how the approach used in this thesis could be useful for research in spearfisheries worldwide.

CHAPTER 2

Study Area and Study Species

Study Area

This study focused on the east and south coasts of South Africa (Figure 2.1). South Africa is unique because it borders two oceans, the Indian Ocean on the east coast and the Atlantic Ocean on the west coast. South Africa's east coast is dominated by the southward flowing, fast and warm Agulhas Current, while the west coast is dominated by the cool northward-flowing Benguela Current (Lutjeharms 2006, Roberts et al 2010). The Agulhas Current moves off South Africa's south coast with the Agulhas Bank and retroflects into the Southern Ocean (Lutjeharms 2006, Roberts et al 2010). The South African coastline consists of four defined biogeographic regions: tropical, sub-tropical, warm- and cool-temperate regions (Potts et al 2015) (Figure 2.1). It is considered a high-energy coastline with constant wave action and storm waves (Smith et al 2010).

Specimens for this study were collected in the sub-tropical, warm- and cool-temperate zones, between Durban (29º 44' S, 31º 4'E) and Cape Point (34º 21'S, 18º 28' E) (Figure 2.1). The samples were speared predominantly on high profile reefs in depths ranging from 5 to 20 m. These reefs run parallel to the shore and have scattered rocky reefs with sand in-between them. The core region of sampling was conducted in the Eastern Cape of South Africa, between East London (33º 2'S, E 27º 51' E) and Cape St. Francis (34º 12' S, 24º 49' E) (Figure 2.1). Water temperatures are highly variable in this region due to coastal and wind-driven upwelling, particularly for the region between Port Alfred and Cape St. Francis (Lutjeharms 2006), which was the core fish collection area. Here, the Port Alfred, Cape St. Francis and other upwelling cells are known to cause significant sea-surface temperature fluctuations of up to 11°C (Hanekom et al 1989). These rapid upwelling-driven events occur mostly in summer, and are known to have significant influences on the seasonal distribution and abundance of fishes (Lutjeharms 2006). Water clarity is highly variable, with wind, currents and upwelling all having an influence.

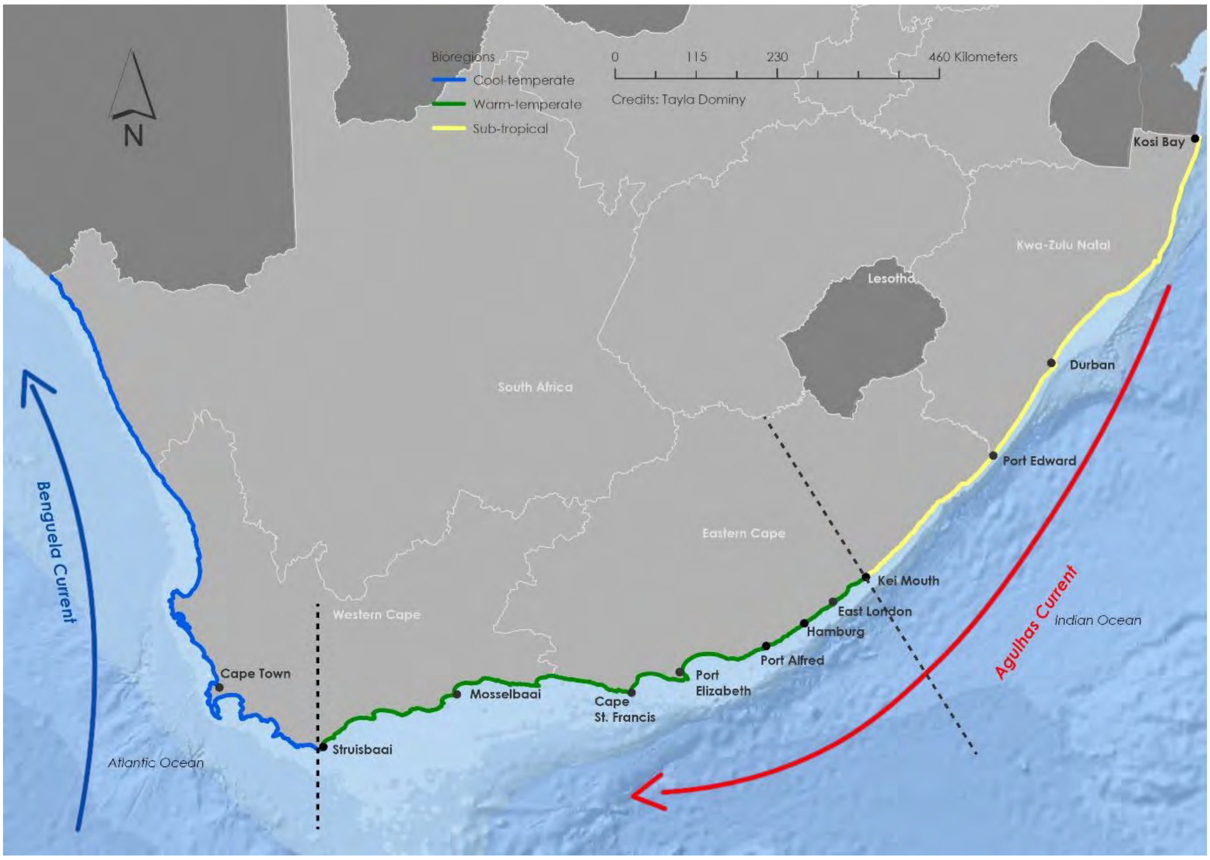

Figure 2.1: Map of Southern Africa representing the three main biogeographic regions and the main towns referred to during this study.

Study Species

The family *Oplegnathidae* comprises seven species belonging to a single genus, *Oplegnathus*. Of the three species found in southern Africa, two (*Oplegnathus conwayi* and *Oplegnathus robinsoni*) are commonly targeted by South Africa's recreational spearfishers (Chater et al 1995). *Oplegnathus conwayi* (Figure 2.2) is endemic to South Africa with a distribution from the Tugela River mouth (KZN) to Cape point (WC) (Chater et al 1995; Mann and Maggs 2013). This species inhabits inshore reefs ranging from 5 to 32m in depth, with juveniles being found in shallower waters (Heemstra and Heemstra 2004). Juveniles are a striking yellow colour with two vertical black lines just behind the mouth and in front of the tail (Figure 2.2, van der Elst 1993). *Oplegnathus conwayi* are currently not listed on the International Union for Conservation of Nature (IUCN) Red List for Threatened species, but are listed on the South African Sustainable Seafood Initiative (SASSI) red list as they are classified as a recreational, no-sale species. Presently, the only species-specific rules for the species is a bag limit of five individuals per person per day and there is no minimum size limit or closed season.

Oplegnathus conwayi are seldom captured using hook and line due to their mouth morphology and feeding habits (Chater et al 1995). However, they are captured in the spearfishery in Kwa-Zulu Natal, the Eastern Cape and Western Cape. Mann et al (1997) found that *Oplegnathus* spp. contributed 28%, 30% and 16% of the spearfishing competition catches in Kwa-Zulu Natal, Eastern Cape and Western Cape, respectively. They also found that it was the sixth main target species by spearfishers in the Eastern Cape and Western Cape, and suggested *O. conwayi* bag limits were often reached.

There is very little biological data on *O. conwayi* with the exception of a preliminary assessment on the biology of the species (Chater et al 1995). These authors examined the growth, feeding behaviour and reproduction of two southern African knifejaw species (*O. conwayi* and *O. robinsoni*) and suggested that *O. conwayi* predominantly feed on sponges, barnacles, sea cucumbers and algae, which they obtain off the reef using their beak-like mouth. Unfortunately, they were unable to collect sufficient specimens to conduct a comprehensive study on their growth and reproduction. However, they estimated a maximum age of 13 years for *O. conwayi*, which was based on the examination of whole otoliths. They also suggested that *O. conwayi* spawn throughout the year with a potential peak period in spring (September – October) (Chater et al 1995). Connell (2012) also reported a peak in *O. conwayi* eggs in Kwa-Zulu Natal in spring, supporting the suggestion of a peak spawning period during this time.

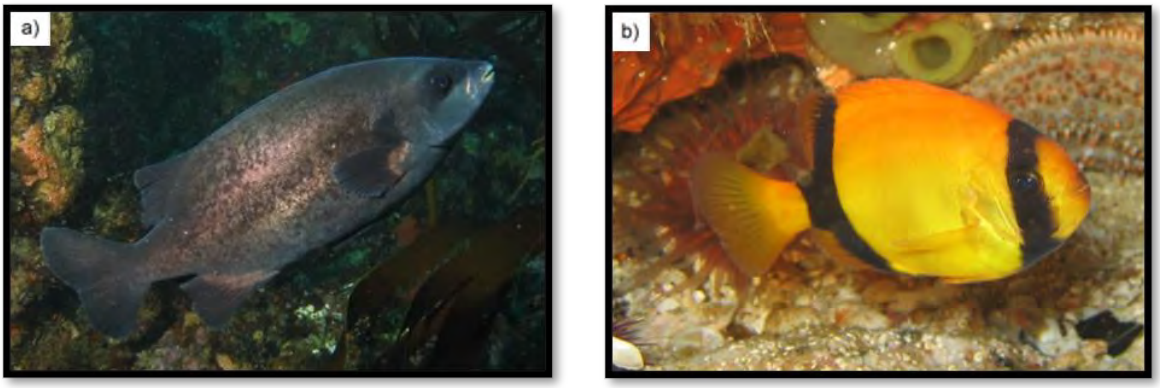

Figure 2.2: Photos accessed from the South African Institute of Aquatic Biodiversity (SAIAB) of a) an adult *Oplegnathus conwayi* and b) a juvenile, taken by a baited remote underwater stereo-video system (BRUV).

CHAPTER 3

The biology and life history of *Oplegnathus conwayi*, an endemic South Africa teleost

Introduction

Research into understanding fish life history characteristics is fundamentally important for fisheries management and the conservation of fish species (King and McFarlane 2003; Young et al 2006). Life history information such as growth rates, age and size of maturity, fecundity and reproductive strategies allows fisheries managers to understand the potential resilience of a species to exploitation (Winemiller 2005). Furthermore, information on the demography, age-and-growth, reproduction, maturity and population structures of species is incorporated into the assessment of fish stocks and allows fisheries managers to make informed management decisions (King and McFarlane 2003; Winemiller 2005; Young et al 2006). Management decisions that are made without the knowledge and an understanding of the life history of target species have been detrimental and have led to population collapses (Hilborn et al 2020). Therefore, the collection of life history information is imperative for resilient socio-ecological systems (SES) in fisheries.

In general, South Africa has a rich history of biological research on its marine fishery species. There is information for the majority of fishes captured in the linefishery. However, there is limited information for many species that are exclusively captured in the spearfishery. These include *Oplegnathus conwayi, Chirodactylus jessicalenorum, Chirodactylus grandis,* and *Oplegnathus robinsoni* (RSA 1998, Mann 2013). This lack of knowledge is concerning and has undoubtedly contributed to the lack of assessment and management (through species-specific regulations) of these species. The consequences for the lack of management may be far-reaching, as population collapses would result in a shift in the target species towards species traditionally captured in the linefishery. This intersectoral conflict would place additional stress on the already stressed SES of the South African linefishery (Potts et al 2020a, see Figure 1.1).

One of the primary reasons for the lack of life history information for fish that are predominantly targeted in the spearfishery is the difficulty of collecting specimens (Carruthers et al 2014). This is because the study species are not readily captured using traditional sampling methods. However, recently citizen science projects, which have encouraged anglers to provide specimens (both whole and without fillets) have been effectively implemented in Australia (Fairclough et al 2014) and South Africa (Hewett 2019), and allowed the collection of sufficient samples for life history and stock assessment research. The *Send us your Skeletons* (SUYS) programme in Australia has proven to be an extremely successful example of this and has dramatically increased data collection while substantially decreasing the costs (Fairclough et al 2014). While large-scale programmes such as this have not been developed in South Africa, the collection of fish skeletons by the recreational sector holds much promise both here and in the rest of the developing world, where research funding is not always readily available for extensive field data collection.

The incorporation of projects such as these would benefit data-deficient fisheries and help collect data on species like that of *O. conwayi*. *Oplegnathus conwayi* form an important component of South African spearfishers' catches and are in desperate need of biological and ecological data for management. With the use of routine sampling methods and augmentation of samples from recreational spearfishers, this chapter aimed to describe the life history of *O. conwayi* in South Africa, namely age and growth, size and age at maturity and reproductive seasonality.

Materials and Methods

Biological data collection

Oplegnathus conwayi specimens were collected monthly between Kenton-on-Sea (30 km west of Port Alfred) and East London (see Figure 2.1) using conventional spearfishing techniques between February 2019 and January 2020. In addition, local affiliated (Border Undersea Club, Gully Jumpers) and unaffiliated spearfishers were asked to donate their catch. Fresh fish frames were collected from volunteers where possible, otherwise, the frames were frozen and collected at a later stage. In addition, two spearfishing competitions in the sub-tropical temperate zone were attended, one at Hole in The Wall (HITW) (Eastern Cape) (161 km east of East London) and one in Durban (KwaZulu-Natal) (see Figure 2.1). Spearfishers were asked to donate their *O. conwayi* catch for the scientific study.

Laboratory processing

In the laboratory, the fork length (FL) and total length (TL) of fish were measured to the nearest mm. Fish were weighed whole, without viscera, and without viscera and gills, to the nearest gram. Fish were then sexed (immature male/female, male and female) and staged according to the macroscopic staging scales adapted from Winkler (2013) and Zhang et al (2010) (Table 3.1 and 3.2). The gonads were weighed to the nearest 0.01g and stored in 10% formalin for later histological analysis. Sagittal otoliths were removed and stored for later preparation and analysis.

Table 3.1: Macroscopic and equivalent microscopic (histological) staging of male *Oplegnathus conwayi* gonads sampled from the Eastern Cape of South African between February 2019 and January 2020. Adapted from Winkler (2013) and Zhang et al (2010).

Stage	Macroscopic description	Microscopic description
1. Immature	Thin and transparent in colour or underdeveloped and appear missing	Spermatogonia dominate the testes
2. Virgin/resting	Testes become identifiable but small and threadlike, appear a white to grey colour	Spermatogonia dominate the testes with an increase in spermatocytes
3. Developing	Increasing in size of testes (swelling), appear white in colour, sperm is not extrudable	Spermatogenesis present, the seminiferous tubules begin to fill with spermatozoa, while the main sperm duct remains empty
4. Developed/Ripe	Swollen testes and white in colour, sperm is extruded when cut or squeezed	All stages of spermatogenesis are present. The mair sperm duct and seminiferous tubules are filled with spermatozoa
5. Spent	Testes appear flaccid and decreased in size, with prominent veins and grey in colour	Stages of spermatogenesis are still present but begi to be dominated by spermatogonia. Less spermatocytes are observed in the seminiferous tubules and sperm ducts

Table 3.2: Macroscopic and equivalent microscopic (histological) staging of female *Oplegnathus conwayi* gonads sampled from the Eastern Cape of South African between February 2019 and January 2020. Adapted from Winkler (2013) and Zhang et al (2010).

Stage	Macroscopic description	Microscopic description
1. Immature	Thin and transparent in colour or underdeveloped and appear missing	Oogonia and perinuclear oocytes present
2. Resting	Orange in colour with minimal veins and eggs not visible	Ovarian tissue dominated by oogonia and perinuclear oocytes
3. Developing	Ovary larger in size with a deeper orange colour, eggs become visible	Development of all oocyte stages, increased quantity of primary vesical, oocytes and some secondary yolk vesical oocytes
4. Developed/Ripe	Bright orange, swollen gonad with large visible eggs	All stages of vitellogenesis present but dominated by tertiary yolk vesicle oocytes
5. Spent	Ovary appears flaccid and blood shot, with a yellow colouration	All vitellogenic oocyte stages present in the ovary, atresia of yolk vesicle oocytes begins

Age and Growth

Otolith preparation, reading and pilot study

A pilot study was conducted to determine the optimal sectioning plane and preparation of the otoliths using the methods proposed by Winkler (2013). Fifteen random otolith pairs were selected and set in clear polyester resin in latex setting trays. Once set, the resin was removed and one of the otoliths were sectioned transversely, while the other longitudinally, between 0.4 and 0.5 mm, to assess the best transitioning plane using a twin-bladed diamond-edged geological saw. Once sectioned, the otoliths were mounted on glass slides using DPX mountant. The otoliths were read under transmitted light, using a low power dissecting microscope (10x – 35x magnification). The author and another independent reader counted the visible opaque zones. A readability index (from 0 = unreadable to 5 = easily readable) was assigned to each otolith to determine which section was most accurate, and the average of readability indices (ARI) was calculated for the transversely and longitudinally sectioned otoliths. The reliability of each growth zone count was assessed using an index of average percentage error (IAPE) calculation (Beamish and Fournier 1981), as below:

$$IAPE = \frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{R}\sum_{i=1}^{R}|\frac{X_{ij} - \bar{X}_J}{\bar{X}_J}\right]$$

where n = aged fish, R = number of times each j fish is aged, X_{ij} = ith age determined for the jth fish, and $\overline{X}_j$= the mean age calculated for the jth fish.

Otoliths sectioned transversely had the lowest (33.8%) IAPE and the highest (3.2) ARI compared to otoliths sectioned longitudinally and thus, the remaining (283) otoliths were sectioned transversely. All the otoliths were read by three independent readers. Otolith counts were accepted if two of the reader's counts coincided, and with counts following succession (e.g. 2, 3 and 4), the middle count was accepted. When assessing older fish (>12), should all three reading counts differ by two or less (e.g. 14, 15 and 17), the counts were accepted, and the middle count was chosen. When counts exceeded 20 and differed by more than two, the closest two counts were averaged (e.g. 26, 28 and 39 was accepted as 27). Otoliths with counts out of these ranges were discarded.

Length-weight relationships

The relationship between fork length (FL) and total length (TL) was expressed using a linear relationship:

$$FL = mTL + c$$

where *m* is the slope and *c* is the intercept coefficient. The relationship between FL and weight (Wt) was described using the following exponential relationship:

$$Wt = \propto FL^{\beta}$$

where α and β are the model parameters to be estimated.

Age validation and increment analysis

Marginal zone analysis was used to determine the seasonality of growth zone deposition. The proportion of otoliths with a hyaline edge were plotted by month over the year.

Growth Model

A three-parameter von Bertalanffy Growth Function (VBGF) (Ricker 1975) was used to model the growth of *O. conwayi* from the observed length-at-age data. This model was selected above other similar growth models due to it having the lowest Akaike's Information Criterion (AIC) value (Booth 1997), making it more statistically robust. The data was modelled using the VBGF equation represented below:

$$L(t) = L_{\infty}\left(1 - e^{-k(t-t_0)}\right)$$

where $L_{(t)}$ is the length of an individual at a given time, $L_{(\infty)}$is the asymptotic maximum length of the population, k is the growth coefficient and t_0 is the theoretical length at age zero. A downhill simplex search routine was used to estimate the model's three parameters (Nelder and Mead 1965). The model's variability was estimated in using a parametric bootstrapping procedure (Efron 1982) with 1000 iterations, from which 95% confidence intervals were constructed. All immature fish were included in both the male and female models to maintain biological realism. Differences in the model parameters of the sexes were tested with a likelihood ratio test (LRT).

Maturity and population structure

The macroscopic staging information was used to determine the maturity of the sampled fish. Fish categorised to be in Stage 1 were considered immature and not likely to spawn during the next spawning season, while fish categorised as Stages 2, 3, 4 and 5 were considered mature. Length- and age-at-50% maturity was calculated by fitting a logistic ogive to the observed proportion of mature fish per length and age class. The two-parameter ogive equations to calculate L_{50} and A_{50} are described below:

$$P(L) = \frac{1}{1 + e^{-(L-L_{50})/\delta}}$$

$$P(A) = \frac{1}{1 + e^{-(A-A_{50})/\delta}}$$

where $P(L)$ and $P(A)$ are the proportion of mature fish at a specific length or age, respectively, δ is the width of the ogive and L_{50} the length-at-50% maturity. The maximum likelihood estimates of the parameters were obtained by minimising the negative binomial log-likelihood function (Winkler 2013). A LRT was used to assess the difference between size- and age-at-maturity between males and females.

Reproduction

Three gonads from each stage (1-5) and sex were selected for histological analysis. The gonads were sectioned transversely through the middle of the gonad. The samples were then embedded in paraffin wax, sectioned at 5-6 microns, stained using haematoxylin and eosin (HE) (Austin and Austin 1989) and mounted on glass slides. Reproductive seasonality was examined by plotting the monthly proportion of fish with resting, developing, ripe and spent gonads. In addition, the monthly gonadosomatic index (GSI) was calculated as:

$$GSI = \frac{gonad\ mass(g)}{eviscerated\ mass(g)}\ X\ 100$$

and expressed monthly.

All analyses were run, and graphs created in R studio and R 3.6.1 (R Development Core Team).

Results

Population structure and morphometrics

In total, 254 fish were collected from the warm-temperate coastal zone (East London – Struisbaai), 28 from the sub-tropical zone (Durban – East London) and 23 from the cool-temperate zone (Cape Agulhas – Cape Point) (Appendix 1, Figure 3.1). The largest proportion (154) of samples came from Kenton-on-Sea in the Eastern Cape (Table 3.3, Figure 3.1). Of the 305 individuals, 105 were males, 58 females, 87 immature male/females and 55 were unsexed (fish received from citizen scientists without gonads). A total of 170 fish were collected through routine sampling methods, while 108 specimens were collected by citizen scientists and 27 in competitions (Table 3.3). The average minimum size of specimens collected by citizen scientists was higher than that of specimens collected through routine sampling. The overall population sex ratio was male dominated at 1 M:0.6 F. The length-frequency distribution for male and female fish were similar with equal proportions of sexes being observed across all size classes (Figure 3.2a).

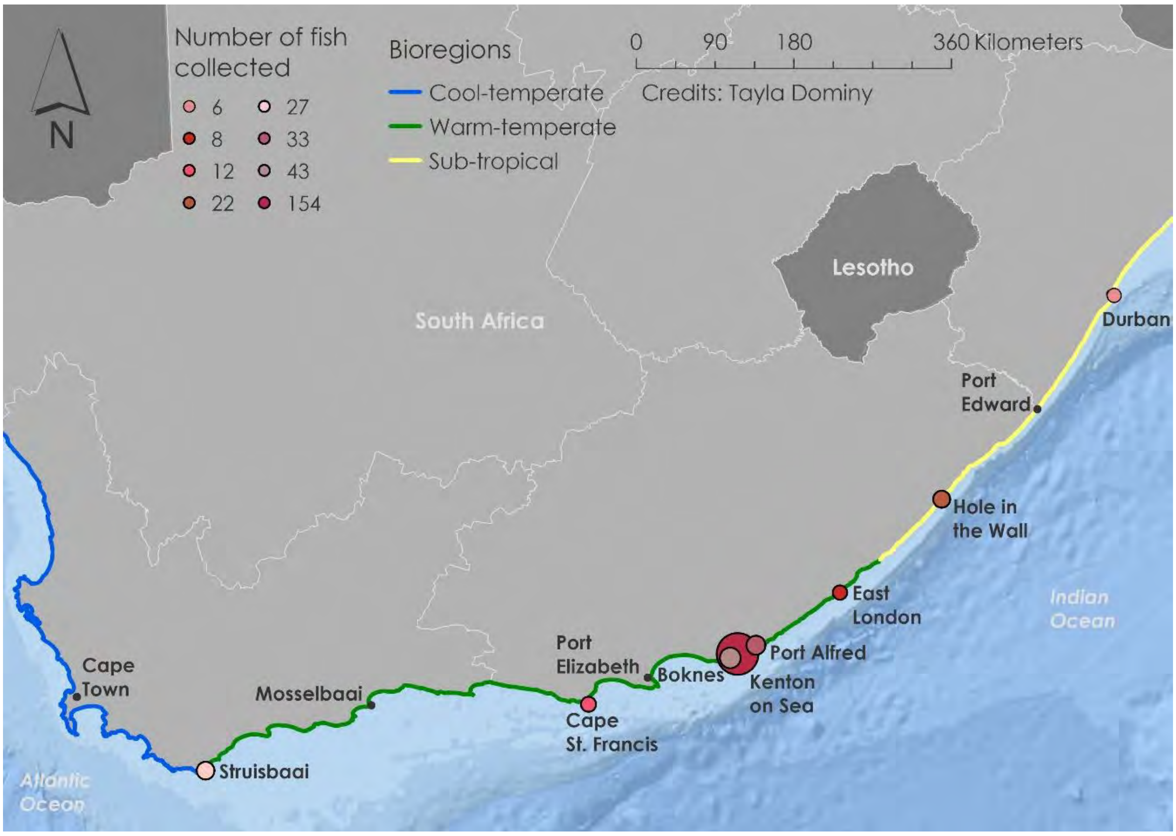

Figure 3.1: Map representing the various collection sites from this study with the proportion of samples collected per site represented by the circle's size at each site.

Table 3.3: Table of all sampling events between February 2019 and January 2020. CS (Citizen scientists), RS (Routine Sampling), C (Competitions), FL (Fork Length).

Date	Location	Collection Method	No. Specimens	Range of lengths (FL)(mm)
2019/02/02	Port Alfred	CS	1	600
2019/02/05	Boknes	RS	9	362-455
2019/02/05	East London	CS	5	380-433
2019/02/06	Kenton-on-Sea	RS	5	199-489
		CS	3	400-415
2019/02/14	East London	CS	3	411-429
2019/03/16	Kenton-on-Sea	RS	7	145-495
		CS	4	322-480
2019/03/19	Kenton-on-Sea	RS	6	329-454
		CS	5	344-472
2019/03/19	Port Alfred	CS	2	400-580
2019/04/26	Kenton-on-Sea	RS	4	293-455
2019/04/27	Kenton-on-Sea	RS	15	200-475
		CS	4	369-455
2019/05/13	Kenton-on-Sea	RS	3	272-445
		CS	2	346-361
2019/05/19	Boknes	RS	4	298-460
		CS	3	401-445
2019/05/20	Kenton-on-Sea	RS	6	298-485
2019/06/01	Kenton-on-Sea	RS	5	310-471
2019/06/04	Boknes	RS	2	319-487
2019/06/15	Hole in the wall	C	21	440-587
2019/06/16	Port Alfred	RS	2	420-485
		CS	2	460-491
2019/06/17	Kenton-on-Sea	RS	3	291-438
2019/07/15 - 2019/07/19	Durban (Nationals)	C	6	500-600
2019/07/24	Boknes	RS	7	231-526
		CS	3	394-428
2019/07/29	Kenton-on-Sea	RS	10	290-526
2019/08/05	Kenton-on-Sea	RS	8	306-480
2019/08/06	Kenton-on-Sea	RS	4	164-240
2019/08/08	Port Alfred	CS	4	349-441
2019/08/10	Boknes	RS	10	232-472
2019/09/09	Boknes	CS	4	389-491
2019/09/10	Kenton-on-Sea	RS	12	277-509
2019/09/10	Kenton-on-Sea	CS	6	241-530
2019/09/10	Port Alfred	CS	4	350-499
2019/09/12	Kenton-on-Sea	RS	7	239-445
2019/09/17	Port Alfred	RS	7	104-467
2019/10/04	Kenton-on-Sea	RS	2	223-525
2019/10/21	Kenton-on-Sea	RS	2	185-402
2019/11/24	Kenton-on-Sea	RS	2	249-471
2019/11/30	Kenton-on-Sea	RS	3	165-284
2019/11/30	Cape St. Francis	CS	3	392-460
2019/11/30	Port Alfred	CS	2	360-374
2019/12/08	Kenton-on-Sea	CS	2	355-384
2019/12/26	Kenton-on-Sea	CS	6	370-475
2019/12/26	Port Alfred	CS	4	371-503
2019/12/28	Port Alfred	CS	7	359-470
2019/12/31	Kenton-on-Sea	CS	3	176-454
2020/01/04	Cape St. Francis	RS	9	251-443
2020/01/15	Kenton-on-Sea	RS	8	179-472
		CS	5	271-468
2020/01/26	Kenton-on-Sea	RS	2	425-479
2020/02/14	Struisbaai	RS	6	391-458
		CS	21	296-459

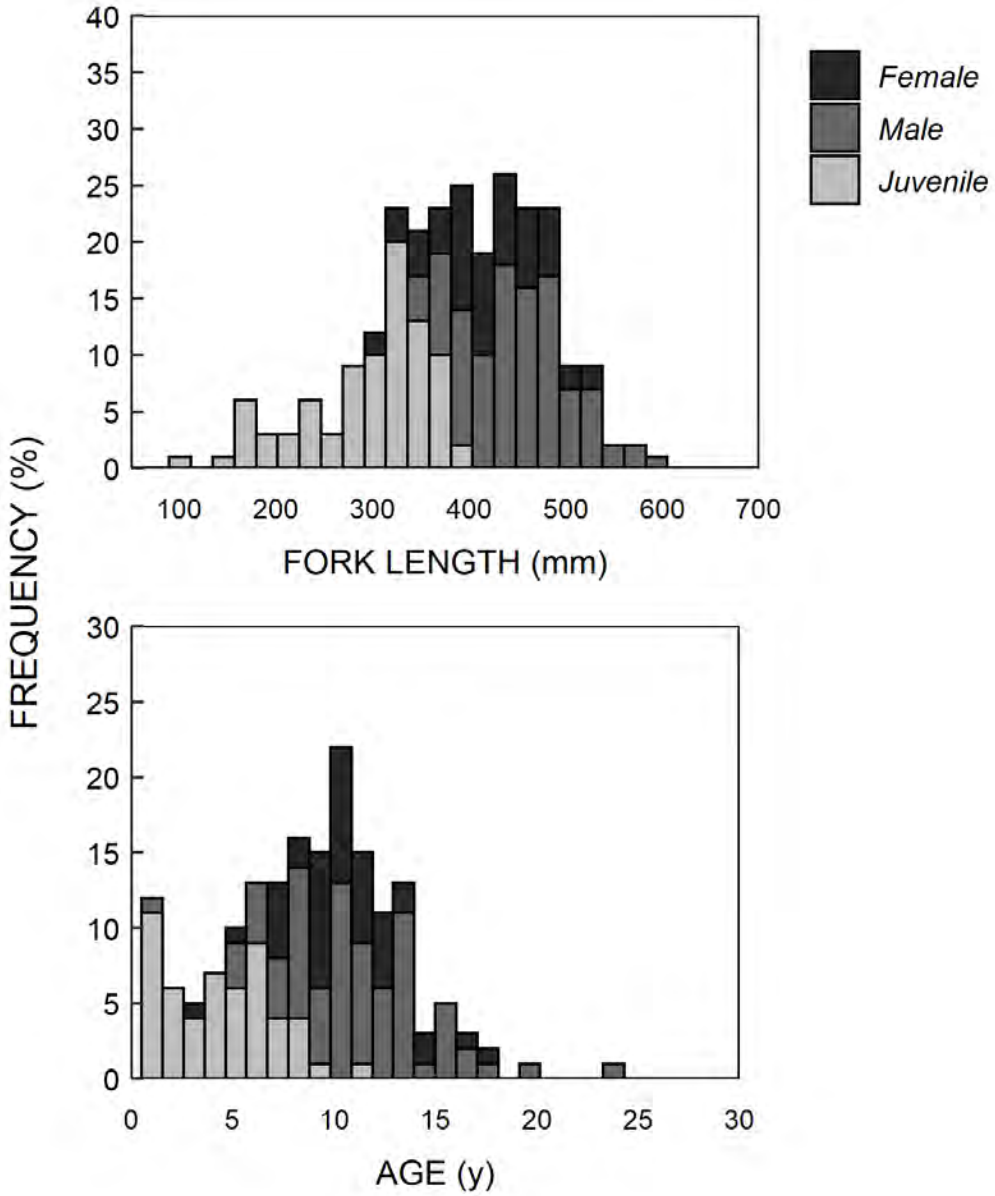

Figure 3.2: Length and age frequency distributions of *Oplegnathus conwayi*, collected between Durban on the east coast of South Africa and Struisbaai on the south coast of South Africa, during the sampling period from February 2019 to January 2020.

The mean fork length and weight were 392 mm (range: 104-600) and 1321g (range: 75-3356), respectively. The relationship between FL and TL was best described by the equation: TL = 1.071(FL) – 2.599 with (r^2 = 0.99) (Figure 3.3a), while the relationship between fork length and mass was best described by the exponential equation: Wt = 0.000029(FL)$^{2.945}$ (r^2 = 0.97) (Figure 3.3b).

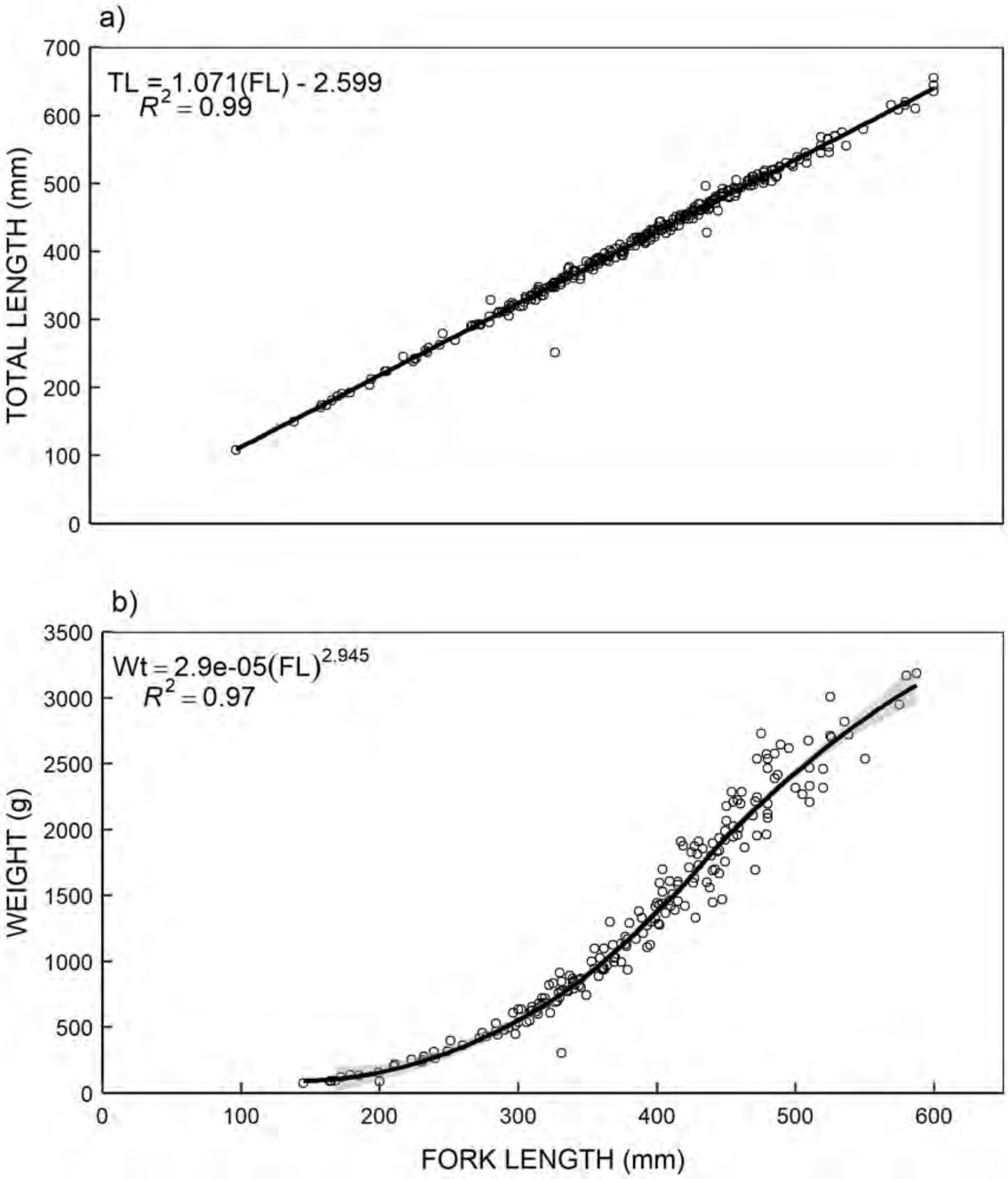

Figure 3.3: The relationship between (a) fork length (FL) and total length (TL) and (b) fork length and weight (Wt) of *Oplegnathus conwayi* collected between Durban on the east coast of South Africa and Struisbaai on the south coast of South Africa, during the sampling period from February 2019 to January 2020.

Age and Growth

Of the 298 otoliths read, 76.9% (229) were accepted, with 73.6%, 89.7% and 95.7% being accepted in the warm-temperate, sub-tropical and cool-temperate zones, respectively. The overall sample IAPE was 21.3%, with 24.2%, 12% and 10.1% for the warm-temperate, sub-tropical and cool-temperate zones, respectively.

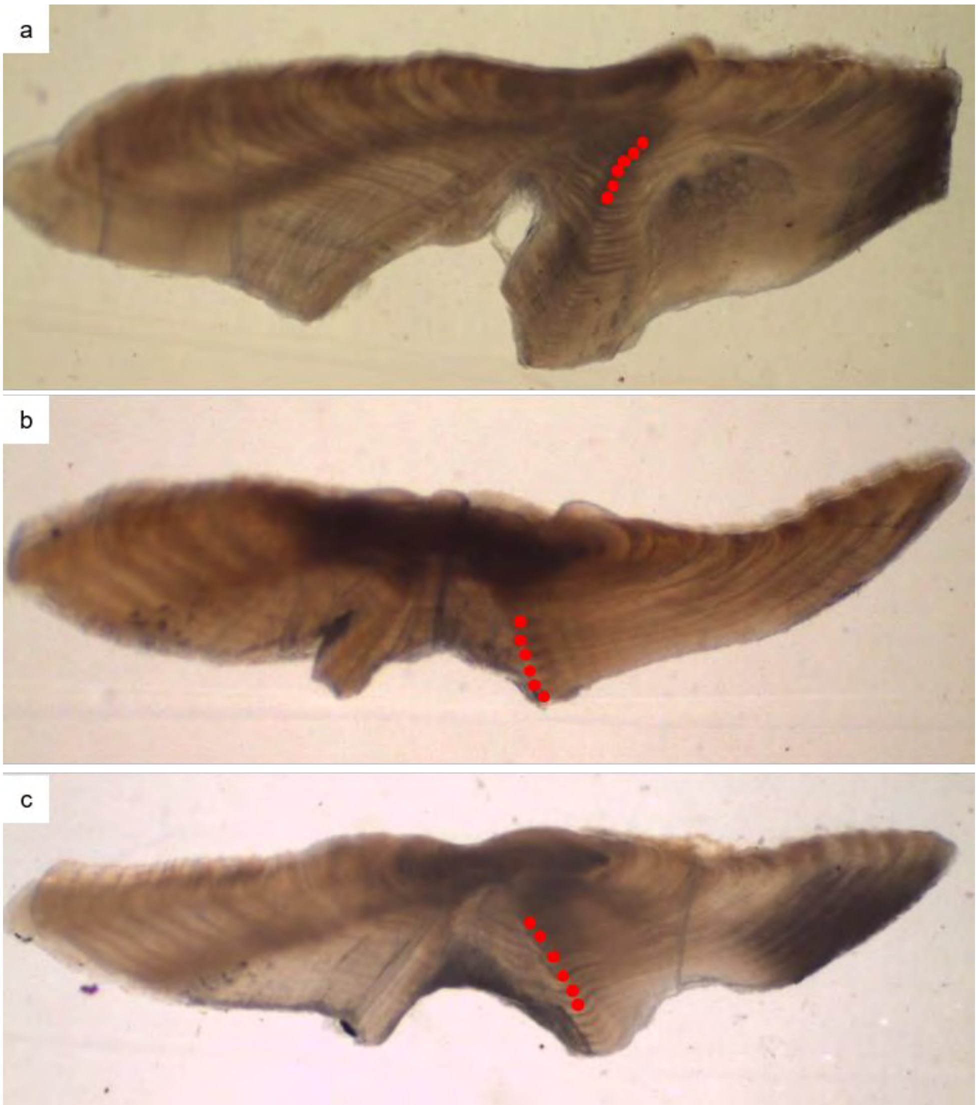

Figure 3.4: Transverse sections of *Oplegnathus conwayi* otoliths from three different biogeographic regions at various ages a) A 27-year-old fish collected in the sub-tropical region off Durban, South Africa (Fish ID ST06-04) b) An immature fish aged six-years old collected from the warm-temperate region off Kenton-on-Sea, South Africa (Fish ID WT08-29) c) A 10-year-old fish from the cool-temperate region collected in Struisbaai, South Africa (Fish ID CT13-22).

Age validation and increment deposition

The marginal zone analysis showed a decline in the proportion of hyaline edges in the otoliths from February and then a clear peak in October (Figure 3.5).

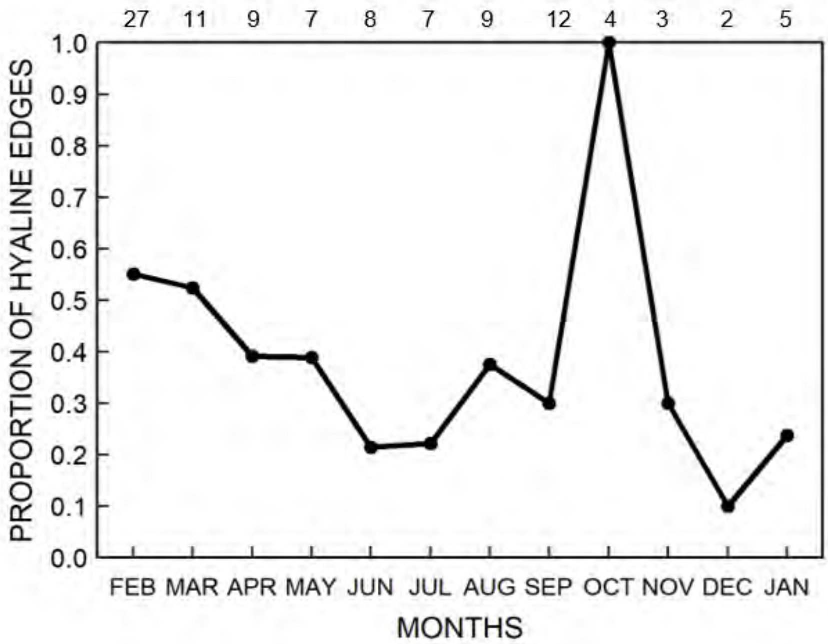

Figure 3.5: The monthly proportion of hyaline edges on the otoliths of *Oplegnathus conwayi*, collected between Durban on the east coast of South Africa and Struisbaai on the south coast of South Africa, during the sampling period from February 2019 to January 2020.

Growth

The oldest unsexed, male and female fish were 27, 24 and 18 years old, respectively. The von Bertalanffy growth equation was $L(t) = 673.76(1-e^{-0.07(t+5.48)})$ for males (Figure 3.6a) and $L(t) = 603.33(1-e^{-0.07(t+5.64)})$ for females (Figure 3.6b). There was no significant difference in growth between males and females (LRT, $p > 0.05$) (Table 3.4) and the growth curve for the pooled dataset was best described as $L(t) = 697.15(1-e^{-0.06(t+6.30)})$ (Figure 3.6c).

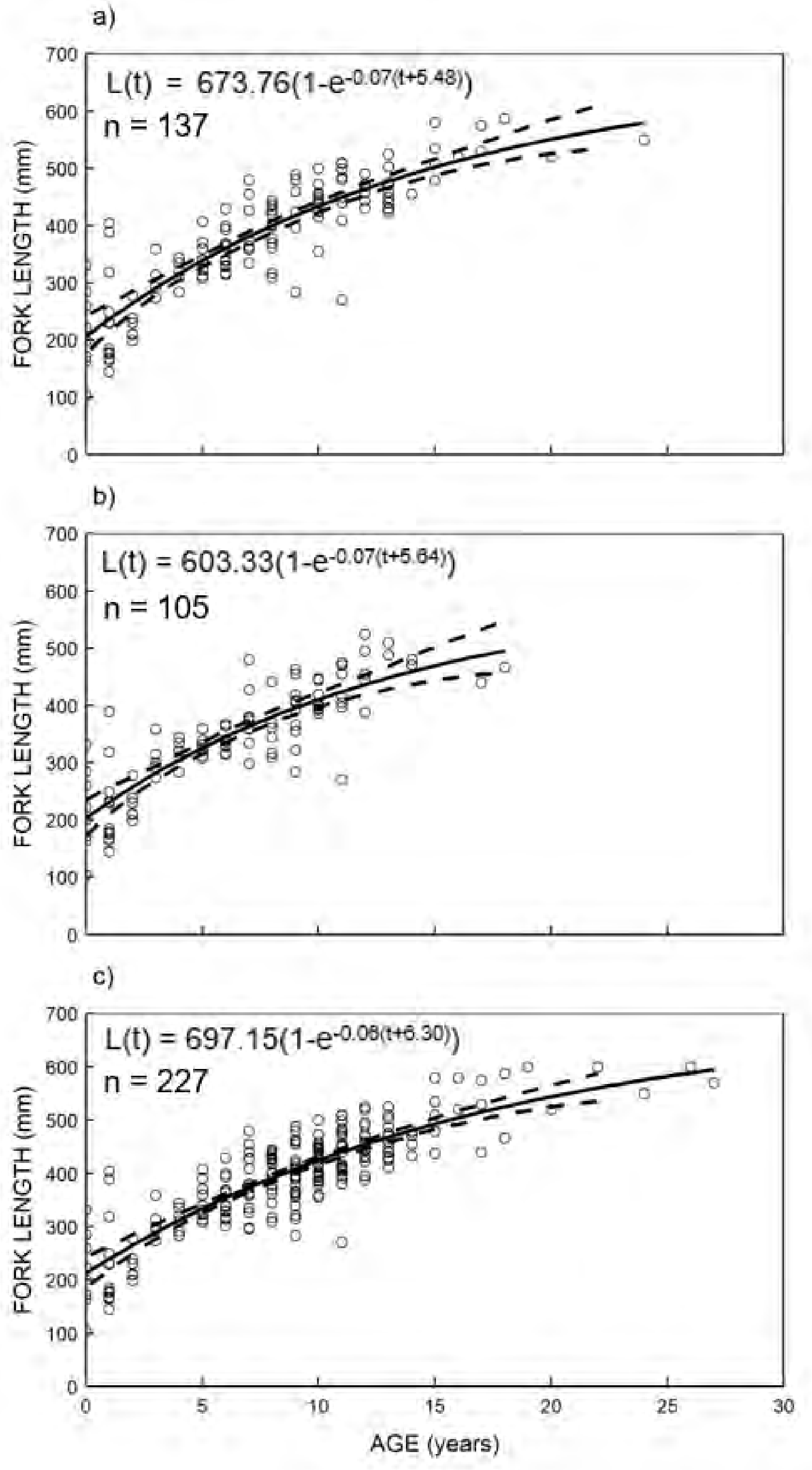

Figure 3.6: von Bertalanffy growth curves for a) male, b) female and c) full population model (combined sexes) for *Oplegnathus conwayi* collected between February 2019 and January 2020 along the east and south coast of South Africa. The dotted line represents the predicted length-at-age at a 95% confidence interval, estimated from the parametric bootstrap.

Table 3.4: Summary statistics and point estimates for the parameters from the von Bertalanffy growth function and the logistic ogive for the whole population (combined sexes), male and female *Oplegnathus conwayi* captured during the sampling period (February 2019 – January 2020) between Durban on South Africa's east coast and Struisbaai on the south coast.

Summary Statistics						
	Parameter	Point estimate	Standard error	Lower 95% CI	Upper 95% CI	δ
Overall population (n=227)	L_∞ (mmFL)	697.15	66.01	599.98	902.88	
	K (years)	0.06	0.01	0.03	0.08	
	t_0 (years)	-6.30	0.97	-8.50	-4.74	
	L_{50} (mm FL)	330.1				22.15
	A_{50} (years)	5.73				1.59
Males (n=105)	L_∞ (mmFL)	673.76	80.44	566.34	959.42	
	K (years)	0.07	0.01	0.03	0.11	
	t_0 (years)	-5.48	1.05	-8.00	-3.82	
	L_{50} (mm FL)	346.59				16.85
	A_{50} (years)	6.42				1.51
Females (n=58)	L_∞ (mmFL)	603.33	107.83	478.07	1154.09	
	K (years)	0.07	0.03	0.02	0.14	
	t_0 (years)	-5.64	1.47	-9.41	-3.36	
	L_{50} (mm FL)	343.63				25.32
	A_{50} (years)	7.07				1.38

<u>Maturity and population structure</u>

The overall population length and age-at-50% maturity was 330.1 mm FL and 5.73 years, respectively (Figure 3.7). Males matured at a slightly larger size (346.6 mm FL) than females (343.6 mm FL), although this was not significantly different (LRT, $p > 0.05$).

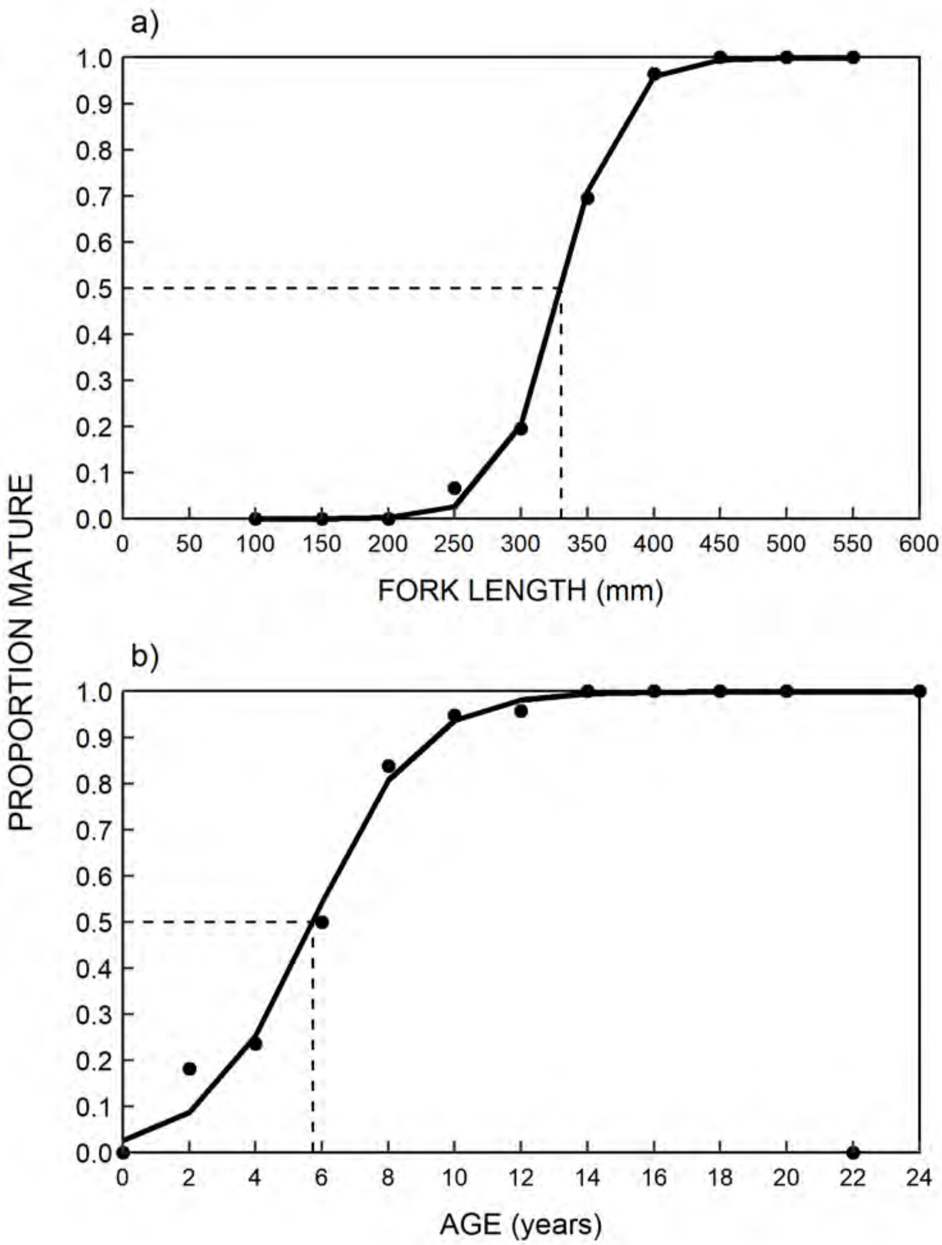

Figure 3.7: a) Fork length and b) age logistic ogives of the combined maturation pattern of male and female *Oplegnathus conwayi*, collected between Durban on the east coast of South Africa and Struisbaai on the south coast of South Africa, during the sampling period from February 2019 to January 2020.

Reproduction

Histological analysis

There was no evidence of hermaphroditism (male and female tissue in a single individual) in any of the sectioned gonads. This suggested that *O. conwayi* are gonochorists and that juvenile fish are born as either male or female with either spermatogonia or oogonia present. Gametogenesis appeared to follow a similar developmental pathway as the barred knifejaw (*Oplegnathus fasciatus*) (Zhang et al 2010) and similar to some species in the family Sparidae (Mann and Buxton 1998, Richardson et al 2011, Winkler 2013).

Spermatogenesis

The testes comprise germinal cells, seminiferous tubules (ST), seminiferous cysts (SC) and sperm ducts (SD). These all work together, allowing spermatogenesis to take place, resulting in the production and release of spermatozoa. *Oplegnathus conwayi* showed four discrete stages of spermatogenesis (Figure 3.8). In the early development stage, spermatogonia (SG) are found in the germinal epithelium, where they proliferate by mitotic division. At this stage, the lumen of lobules are not yet present, but the testicular lobules begin to develop (Figure 3.8a). Once divided, spermatogonia mature into primary spermatocytes (PSC) with small and dense nuclei (Figure 3.8b), which then develop further through meiotic division and become secondary spermatocytes (SPC) (Figure 3.8c). In the late stages of development, the secondary spermatocytes congregate on the outer edge of the seminiferous cysts (SC) and finally rupture into the seminiferous tubules (ST) (Figure 3.8c). Once released into the seminiferous tubules, spermatids (SPT) mature into spermatozoa, (SZ) have a highly basophilic nucleus and are small in size (Figure 3.8d). Presence of spermatozoa in the lumen of the lobules and the sperm ducts is indicative of a mature gonad, and that a fish is ready to spawn. On completion of the spawning season, the regression of testis begins, which is characterised by a reduction in the quantities of spermatozoa in the sperm ducts and lumen of lobules. Spermatocytes observed were all in the late stages of spermatogenesis. The proliferation of spermatogonia was also observed at the periphery of the testis (Figure 3.8e).

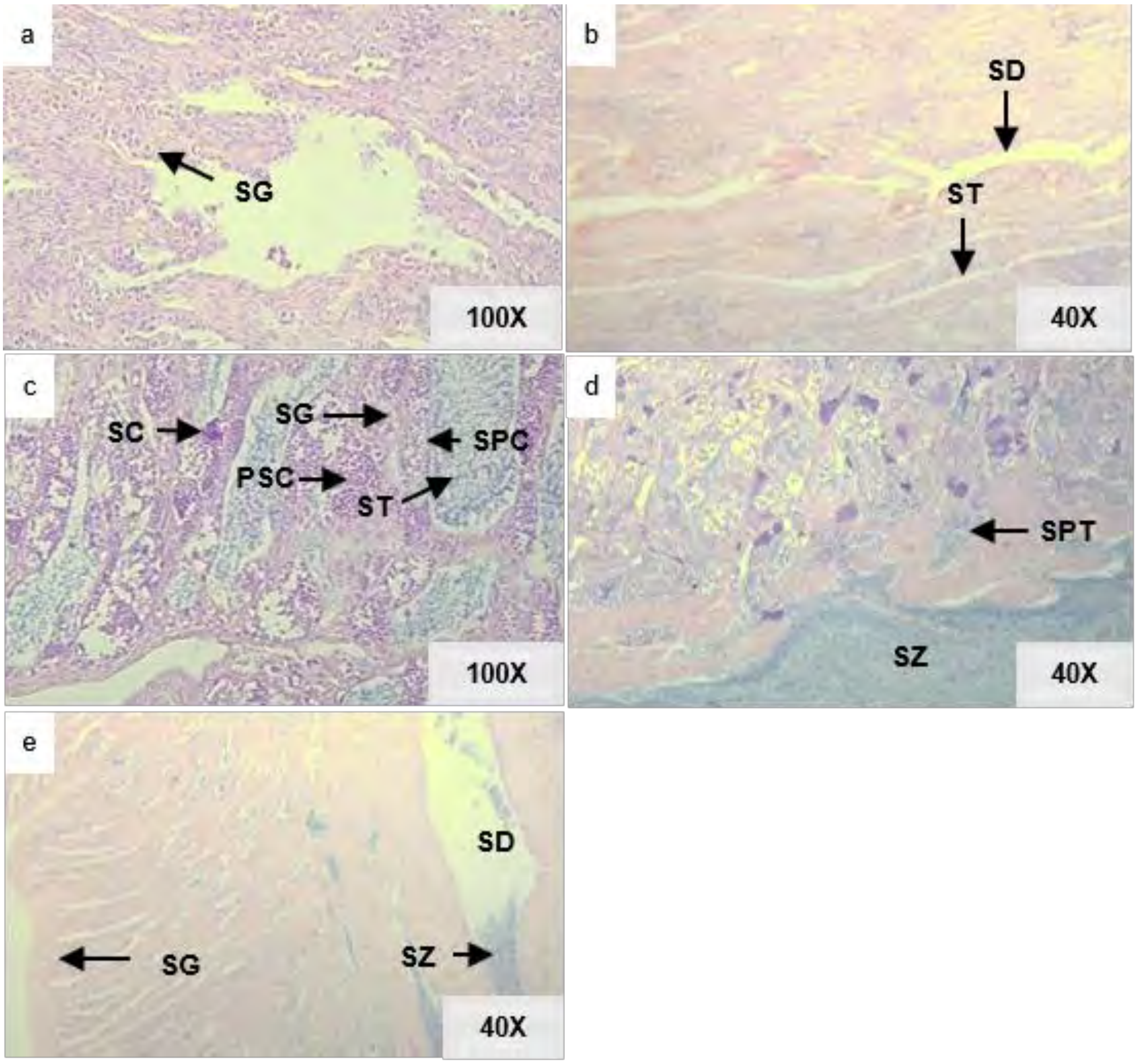

Figure 3.8: Transverse histological sections of *Oplegnathus conwayi* testes depicting the various stages of spermatogenesis and the macroscopic stages microscopically (a-e). (a) An immature gonad with large quantities of spermatogonia (SG). (b) A virgin/resting testis with empty sperm ducts (SD) and seminal tubules (ST). (c) A developing testis with spermatogonia (SG), primary spermatocytes (PSC), secondary spermatocytes (SPC) within seminiferous cysts (SC) and spermatids (SPT) within seminal tubules (ST). (d) A developed/ripe testis with ruptured seminal tubules filled with spermatids (SPT) and sperm ducts filled with spermatozoa (SZ). (e) A spent testis with a reduction of spermatozoa (SZ) in the sperm ducts and spermatogonia (SG) proliferation at the periphery of the testis.

Oogenesis

Pre-vitellogenesis

Oogonia stage

Irregularly shaped oogonia (OO) were mainly found in immature egg nests as well as at the periphery of the ovarian lumen (Figure 3.9a). They were characterised as olive or oval-shaped and were the smallest germ cells. The cytoplasm was small with a large nucleus (Figure 3.9a). Chromatin nuclear oocytes (CN) were also found in immature egg nests (Figure 3.9a) and were more round in shape compared to oogonia and had a large basophilic central nucleus (Figure 3.9a).

Perinuclear stage

This phase consists of three levels of oocyte maturation from oogonia. Early phase perinuclear oocytes are known as pre-perinuclear oocytes (PPO), which are polygonal in shape and contain between four and seven nucleoli. A layer of follicular cells was found on the outside of the cell and the cytoplasm was basophilic (Figure 3.9b). Early phase perinuclear oocytes (EPO) were characterised by an increase in both nucleoli (three to four large ones and multiple small ones) and volume compared to the smaller PPO's. Additionally, oil droplets could be observed in the cytoplasm (Figure 3.9b). Late perinuclear oocytes (LPO) represent the last stage and were the biggest oocytes, being more spherical in shape, containing small scattered oil droplets in the cytoplasm and had a less basophilic cytoplasm. Nucleoli were found neatly arranged around the inner periphery of the nuclear membrane (Figure 3.9c).

Vitellogenesis

Primary yolk vesicle stage

The primary yolk vesicle stage (PYV) is the beginning of vitellogenesis and was characterised by interspersed oil droplets among the yolk in the cytoplasm, yolk granules appearing on the periphery of the oocyte or nucleus and the formation of cortical alveoli (CA). Cortical alveoli are often found on the periphery of the cytoplasm. The radiation zone begins to develop with the outer membrane thickening and the zona radiata (ZR) developing (Figure 3.9d).

Secondary yolk vesicle stage

The oocyte continues to develop and grow in this stage, showing large yolk globules throughout the cytoplasm. The main characteristic of this stage was the development of cortical alveoli rows on the exterior of the nucleus and on the periphery of the cytoplasm (Figure 3.9e).

Tertiary yolk vesicle stage

This is the final stage of vitellogenesis and oocyte maturation. Early in this stage both the zona radiata and the zona granulosa (ZG) were well-developed and easily identifiable (Figure 3.9f). The cytoplasm was filled with yolk particles and became acidophilic. Several large oil droplets were formed in the nuclear region of the cytoplasm, from the fusing of oil globules (Figure 2.8g). As the oocyte developed further, the radiation zone began to thin and the nucleus began to shrink while migrating to the periphery of the cytoplasm (nuclear polarisation). The migration of the nucleus to the oocyte's periphery indicates the completion of vitellogenesis and means the oocyte is ready to be spawned (Figure 3.9h). Prior to ovulation, oocytes increased markedly in size and some became hydrated (Figure 3.9i). The latter not commonly seen in this study, however, as hydrated oocytes had the tendency to collapse during sectioning.

Atresia

This stage was difficult to describe in this species, however, two gonads staged as spent macroscopically were observed as spent microscopically. Spent gonads are characterised by major reductions in size of oocytes, presence of post-ovulatory follicles (POF's) and evidence of oocyte reabsorption (granular appearance and breakdown of zona radiata) (Figure 3.9j).

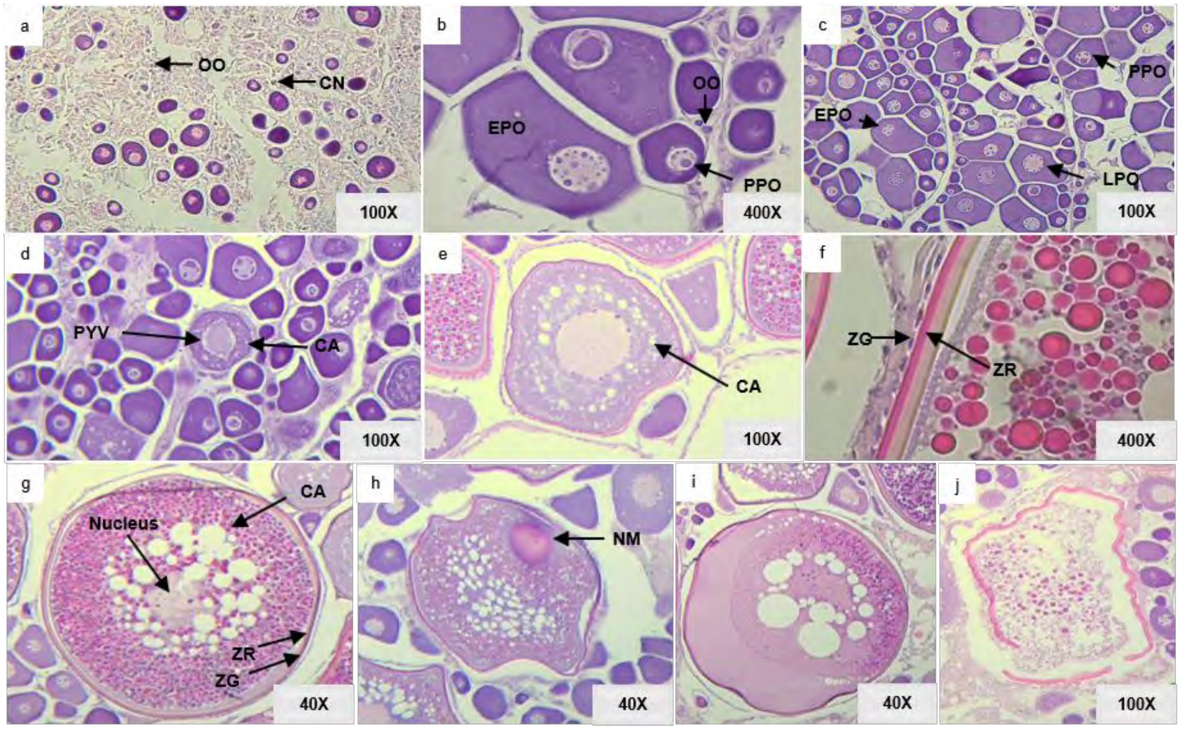

Figure 3.9: Transverse histological sections of *Oplegnathus conwayi* ovaries depicting the various stages of oogenesis and the appearance of the macroscopic stages microscopically (a-j). (a) An immature ovary with large quantities of oogonia (OO) and chromatin nuclear oocytes (CN). Virgin/resting ovaries with (b) Pre-perinuclear oocytes (PPO) and early phase perinuclear oocytes (EPO) and (c) all perinuclear stages, from PPO - late-perinuclear oocyte's (LPO). Developing ovaries with (d) perinuclear stages and the first stage of vitellogenesis (primary yolk vesicle oocyte (PYV)), indicated by the presence of cortical alveoli (CA) and (e) a secondary yolk vesicle (SYV) indicated by cortical alveoli rows at the exterior of the nucleus and the periphery of the oocyte. Developed/Ripe ovaries with (f) zona granulosa (ZG) and zona radiata (ZR) characterizing the development of tertiary yolk vesicle oocytes, (g) a fully developed tertiary yolk vesicle oocyte (TYV) with the migration of oil droplets to the nucleus, (h) nucleus migration (NM) in a tertiary yolk vesicle oocyte indicating the end of vitellogenesis, (i) mature hydrated oocyte. (j) A spent ovary with the start of oocyte reabsorption indicated by a granular appearance and the breaking down of zona radiata (ZR).

Histological validation of macroscopic staging

Immature gonads were dominated by germ cells with early-stage male or female gametogenesis dispersed amongst these. Primary spermatogonia were present in male fish, while oogonia and primary growth oocytes were present in female fish (Figure 3.8a and 3.9a, respectively). Resting/virgin fish had few germ cells with oocytes and spermatogonia dominating the ovary and testis, respectively (Figure 3.8b and 3.9b). The testes of male fish were dominated by primary spermatogonia and primary spermatocytes in the resting/virgin stage, with both the seminiferous tubules and sperm ducts empty (Figure 3.8b). The gonads of female fish in this stage were dominated by oogonia, perinuclear oocytes and primary growth oocytes (Figure 3.9b).

The developing stage of ovaries and testes were generally identified by an increase in size and development in the gonad. The testes showed all stages of spermatogenesis (primary and secondary spermatocytes, secondary spermatogonia, spermatid and spermatozoa). In developing testes, the seminiferous tubules were filled with spermatozoa, while the sperm ducts and lumen of lobules were still empty (Figure 3.8c). In females, the presence of cortical alveoli and early vitellogenic oocytes (PYV and Secondary yolk vesicle (SYV)) signified the development of the ovary (Figure 3.9c).

Ripe gonads were easily identifiable due to their large size and readiness to release spermatozoa and mature oocytes. In this stage, the testes have large amounts of spermatozoa in the sperm ducts and lumen of lobules, and all stages of spermatogenesis were still present/visible (Figure 3.8d). In this stage, female ovaries were filled with large tertiary yolk vesicles (TYV) and hydrated oocytes were observed in some (Figure 3.9d).

The spent stage proved difficult to identify, and gonads staged as spent often appeared as resting/virgin gonads. Male fish were slightly easier to stage as spent, with spent testes containing residual spermatozoa in the lumen of lobules and sperm ducts. Additionally, the proliferation of spermatogonia was observed at the periphery of the testes (Figure 3.8e). Females observed in this stage still had TYV's with atresia occurring in some. Post ovulatory follicles were also observed, indicating that fish had spawned (Figure 3.9e).

Most of the macroscopically staged gonads (25 of 29) matched the microscopic stages. Two visually staged spent females, were actually spent males, while one of the visually staged spent males, was actually resting. The final misinterpretation was a resting male that was visually staged as developing.

Reproductive seasonality

With the exception of January, developing gonads were observed throughout the year for *O. conwayi.* Males with ripe gonads were found in September and November (Figure 3.10a). In contrast, females with ripe gonads were observed in March, September, October and January (Figure 3.10b). Male GSI remained relatively stable throughout the year, with a single peak in December (Figure 3.11a). However, this could be attributed to one individual that had a GSI of 1.23 (Figure 3.11a). There was no clear peak in female GSI, although peaks in GSI were observed in June, October and December (Figure 3.11b).

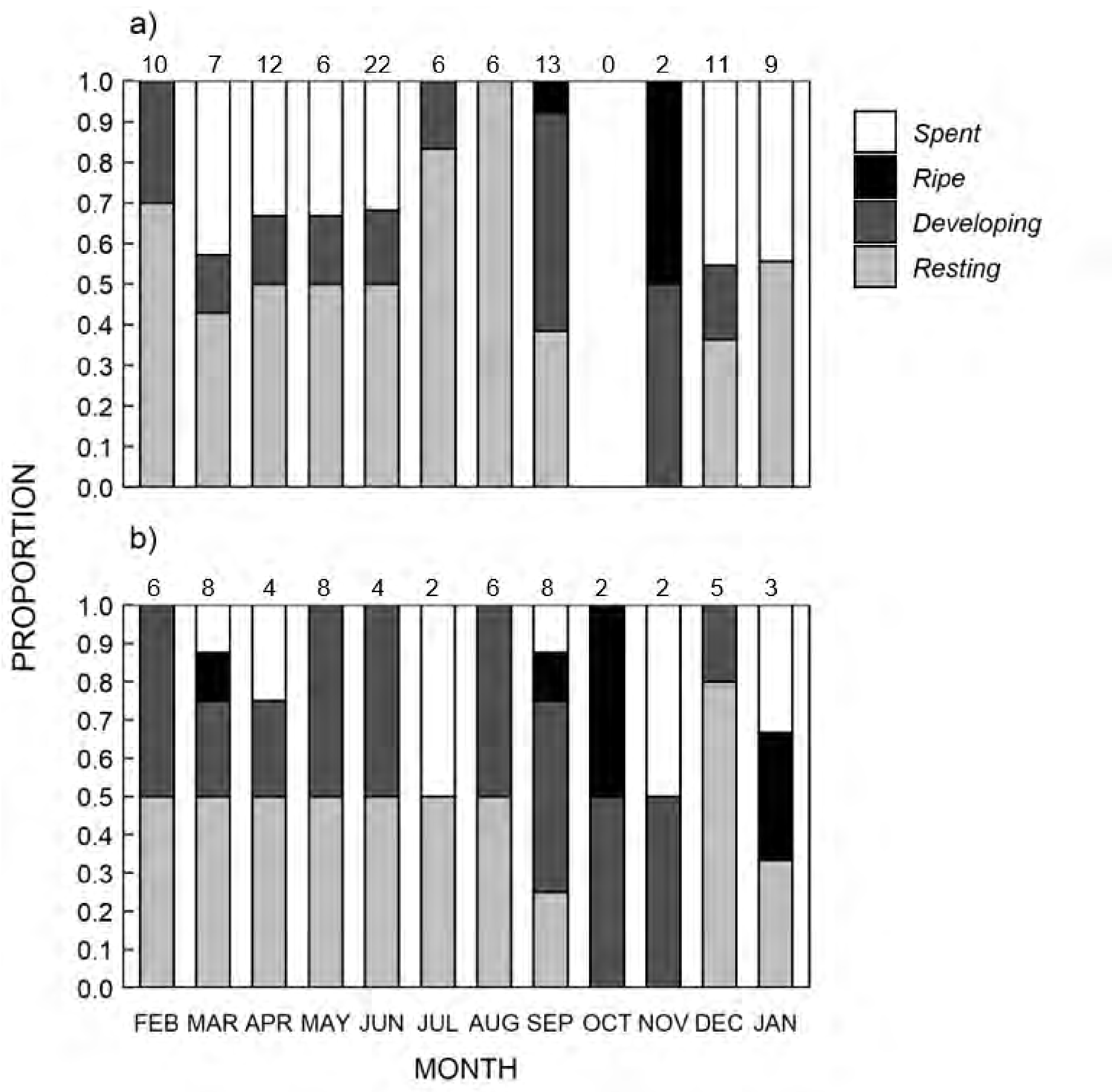

Figure 3.10: Monthly proportion of macroscopic stages for mature (a) male and (b) female *Oplegnathus conwayi* gonads collected in the warm-temperate zone of South Africa between February 2019 and January 2020. The monthly sample size is depicted above the columns.

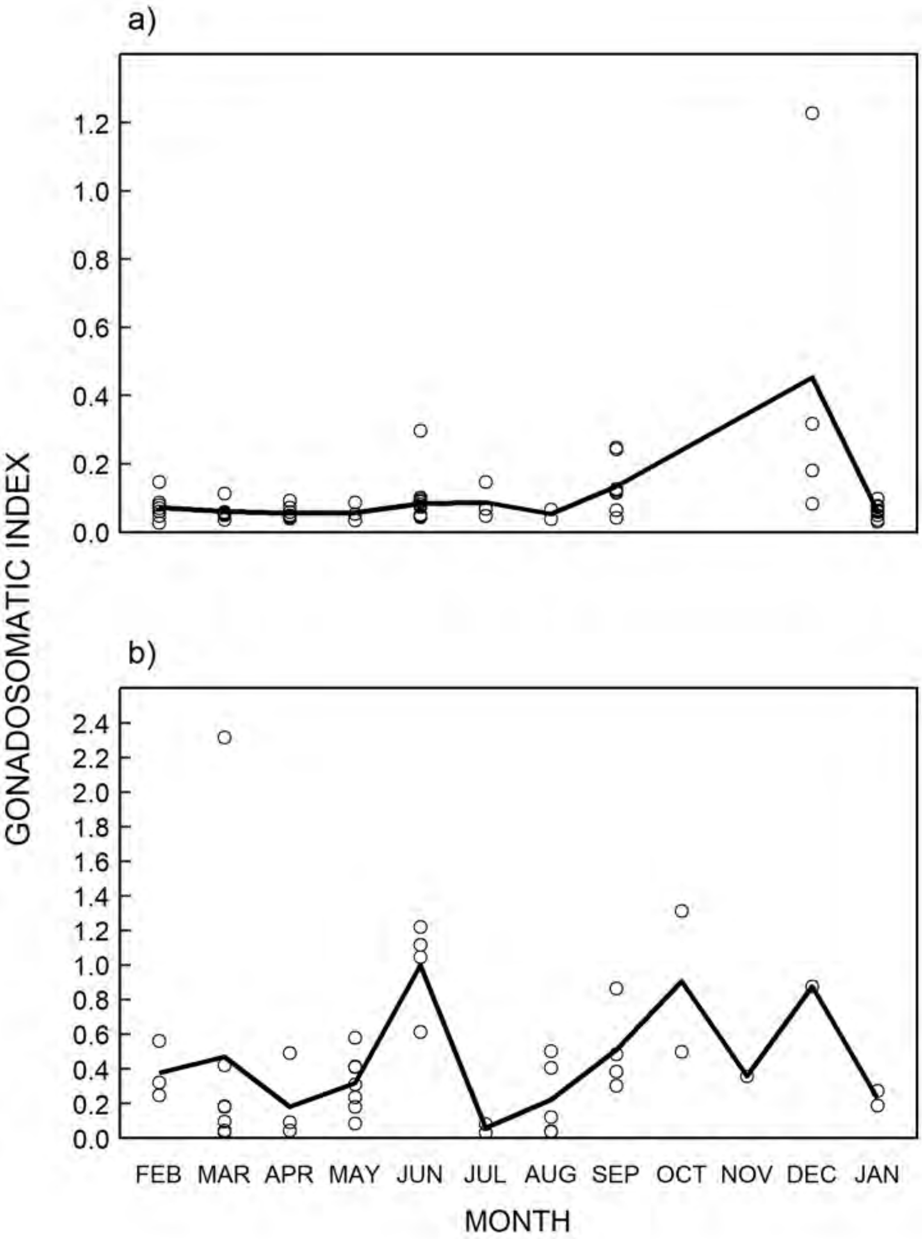

Figure 3.11: Monthly gonadosomatic index (GSI) values for (a) male and (b) female *Oplegnathus conwayi*, collected between February 2019 and January 2020 in the warm-temperate coastal zone. The mean is represented as a line graph.

Discussion

The collection of biological data on *O. conwayi* proved to be successful, with valuable life history information obtained. Traits such as slow growth, late maturation, high fecundity and protracted spawning suggest that this species has a periodic life history strategy (Winemiller

2005). Many of South Africa's marine fish species have taken up this strategy to allow these species the best chance of survival in a highly dynamic and variable coastal environment. Unfortunately, life-history traits such as these may make this species susceptible to overexploitation (Buxton and Clarke 1986, Griffiths 2000, Murray 2012). While these traits have been blamed for the stock collapse of many South African fishes targeted by the multisectoral (recreational and small-scale shore- and boat-based) linefishery (Potts et al 2020a), *O. conwayi* is only targeted by the spearfishing sector and their population may therefore be more resilient. However, as participation in this fishery increases and other target species decline, it is likely that the population may be threatened.

Accuracy and precision aging is critical when conducting stock assessments and designing management regulations for fishes (Campana 2001). The maximum age recorded for *O. conwayi* by Chater et al (1995) was 13 years. This was based on whole otolith readings of a fish of 510 mm FL and was far younger than the 27 years for a fish of 600 mm FL observed in this study. Based on the findings of this study, a 510 mm FL fish would be 16 years of age and this suggests that Chater et al (1995) may have underestimated the age due to reading whole otoliths. This is unsurprising, as studies have shown that reading whole otoliths under-ages older fish (Winkler et al 2019). This underestimation can be detrimental if used in management and would result in an overestimation of the stock status, which would lead to the overexploitation of species. Therefore, it is imperative to obtain the maximum age of the fish in the population and thus every attempt should be made to obtain samples of the largest fish in the population.

Calculating the growth rate of species is important for stock assessment calculations and preliminary management measures. South Africa's marine teleost's have extremely variable growth rates, with species like *Seriola lalandi* and *Scomberomorus commerson* having fast growth rates, while *Chrysoblephus gibbiceps, Cymatoceps nasutus* and *Pachymetopon grande* have slow growth rates and high longevity (Table 3.5). Longevity and slow growth are common in many species targeted in South Africa's linefishery (Table 3.5) and the growth of *O. conwayi* was comparable to that of *Chrysoblephus lacticeps* and other South African Sparids that occupy the same habitat (Table 3.5). As demonstrated by a large proportion of South Africa's Sparids, this slow growth has the potential to pronounce the effects of exploitation and can lead to significant population declines if management measures are not put in place (Smale and Punt 1991, Bennett 1993, Griffiths 2000, Murray 2012 and Hewett 2019). This suggests that, if managed incorrectly, *O. conwayi* may suffer the same fate.

Table 3.5: Main target species in the South African recreational fishery with IUCN (International Union for Conservation) listings, stock status and growth rates. IUCN listings: EN (endangered), VU (vulnerable), NT (near threatened), LC (least concern), and DD (data deficient). Target Sectors: R (rod and line), S (spearfishing), SB (subsistence); B (boat-based rod and line); C (commercial). Biogeographic regions: ST (sub-tropical), WT (warm-temperate) and CT (cool-temperate). Source: Mann (2013)

Family	Species	Common Name	IUCN Listing	Stock Status	Size at Maturity (cm)	Maximum Age (years)	Maximum Size (cm)	Growth Rate	Target Sectors	Biogeographic region
Carangidae	*Lichia amia*	Leerie (Garrick)	LC	Collapsed (<25%)	80	10	180	Fast	R;S;SB;B	All
	Seriola lalandi	Cape yellowtail	LC	Optimally exploited	47 -84	21	143	Fast	S;SB;B;C	All
Dichistiidae	*Dichistius capensis*	Galjoen	N/A	Collapsed (<25%)	31-34	12	47	Slow	R;S;SB	WT;CT
	Umbrina robinsoni	Bardman	DD	Collapsed (<25%)	37-48	16	60	Slow	R;S;SB	All
Scombridae	*Scomberomorus commerson*	King mackerel (couta)	NT	Optimally exploited	68	14	220	Fast	S;B	ST
	Scomberomorus plurilineatus	Queen mackerel (Natal snoek)	DD	Optimally exploited	75	6	117	Fast	S;B	ST
Serranidae	*Epinephelus andersoni*	Catface rockcod	NT	Optimally exploited	43-50	11	87	Medium	R;S;B	ST;WT
Sparidae	*Chrysoblephus gibbiceps*	Red stumpnose	EN	Not assessed (assumed <5%)	21-25	48	45	Slow	S;B;C	WT;CT
	Chrysoblephus lacticeps	Red roman	N/A	Optimally exploited	18	17	51	Slow	S;B;C	WT;CT
	Cymatoceps nasutus	Black musselcracker	VU	Not assessed (assumed <20%)	53	45	109	Slow	R;S;SB;B	All
	Diplodus capensis	Blacktail	LC	Not assessed	15-16	20	35	Slow	R;S;SB	All
	Lithognathus lithognathus	White steenbras	EN	Collapsed (<25%)	65	25-30	138	Medium	R;S;SB	All
	Pachymetopon blochii	Hottentot	LC	Optimally exploited	20-22	21	54	Slow	S;SB;B;C	WT;CT
	Pachymetopon grande	Bronze bream	NT	Not assessed	30	38+	65	Slow	R;S;SB	ST;WT
	Sparodon durbanensis	White musselcracker	NT	Not assessed (assumed <20%)	35	31	103	Medium	R;S;SB	All

Many South African linefish are susceptible to recruitment overfishing, which is where there are insufficient adults in the population to promote sufficient recruitment (Allen et al 2013). However, in the case of *O. conwayi*, it appears that the current behaviour of spearfishers, who generally only target this species when it is above 400 mm FL (which is considerably greater than the size-at-maturity, 330 mm FL) allows the majority of individuals the opportunity to spawn at least once. This behaviour will certainly provide *O. conwayi* with some resilience to exploitation, much like the slow growing, late maturing Sparid, *Dentex macropthalmus* (Potts et al 2010). However, any reduction in the population due to overexploitation may cause a shift (reduction) in target size and would have a negative impact on the reproductive potential of the population.

Understanding population sex ratios is of critical importance when determining potential exploitation risks. The occurrence of uneven sex ratios in fish is common, with a large proportion of South African species having skewed sex populations (Smale 1988, Griffiths et al 2002). Although male biased sex ratios are commonly associated with hermaphroditic species (van der Walt and Mann 1998), the histological evidence from this study provided evidence for gonochorism. Males dominated the larger size (Figure 3.2) and older age (Figure 3.2) classes of *O. conwayi*. This may suggest that the energy dedicated to reproduction by females is larger and has a negative impact on their survival, when compared with males. It is also possible that the sampling technique may have caused a bias in the sex ratio estimate. This is because spearfishers are more likely to capture bolder fish from the population (Sbragaglia et al 2018). Although, there is no evidence for greater boldness in males of *O. conwayi*, this has been observed in other fishes (eg. *Poecilia reticulate*, Piyapong et al 2010). To better understand if exploitation has played a role in driving the observed sex ratio, future studies should collect samples from longstanding Marine Protected Areas (MPA) and then the unexploited and exploited sex ratios should be compared.

The diagnosis of the sexual pattern of fishes is critical for a better understanding of the life history of species. de Mitcheson and Liu (2008 and 2009) suggested that, while several lines of evidence can provide supporting evidence for the diagnosis of sexual patterns, a histological analysis provides the most rigorous direct evidence. Several findings in this study, including males and females growing at similar rates and maturing around similar sizes and ages, similar length and age frequency histograms for both sexes and macroscopic examination of the gonads provided supporting evidence for gonochorism. The most direct evidence for gonochorism was the histology, which showed that juvenile *O. conwayi* are born as either males or females and remain that sex for the remainder of their lifespan. This is not unusual for this family as Zhang et al (2010) diagnosed the closely related *O. fasciatus* as a gonochorist.

The histological evidence (various developmental stages observed in ripe ovaries), together with the GSI and macroscopic staging, indicated that *O. conwayi* are asynchronous spawners. This also aligns with Zhang et al (2010) who found a similar, asynchronous development pathway for *O. fasciatus*, and was similar to another coastal fishery species in South Africa, the Galjoen (*Dichistius capensis*) (Bennett and Griffiths 1986; Attwood and Mann 2012). The peak reproductive season of *O. conwayi* was difficult to determine due to low sample sizes in certain months. Nevertheless, the GSI and macroscopic staging evidence did suggest that the spawning period was protracted with a potential peak in spring and summer. Chater et al (1995) also indicated that *O. conwayi* have a protracted spawning period, with developing gonads observed during most months of the year. The potential peak in ripe gonads and GSI observed for *O. conwayi* in spring and summer coincides with a large proportion of Southern Africa's reef fish species (Buxton and Clarke 1986, Buxton 1990, Hutchings and Griffiths 2010, Attwood et al 2019, Attwood and Ensair 2020) and has been attributed to the mix of east and west winds, which support high levels of nutrients and primary productivity along South Africa's east coast (Lutjeharms 2006). These conditions ensure that there is an abundance of food for larval fish (Sheaves 2006). While these conditions support productivity, the conditions for diving are often unfavourable and this explains the poor sample sizes collected during these months. Therefore, future studies should aim to collect additional specimens during this period to provide better clarity on the spawning season of this species.

There were several limitations in this study and they should be considered when assessing the validity of these findings. The validation of the growth zone deposition is critical for accurate aging and, while a variety of methods can be used for validation, many, such as chemical marking and recapture were not possible due to the collection method of this species. Marginal zone analysis is not considered to be one of the robust methods of validating growth (Campana 2001), particularly when sample sizes are low in some months. Despite this, there was a clear peak in hyaline growth bands during spring for *O. conwayi.* The deposition of a single opaque and hyaline band is common among many coastal species that share the environment with *O. conwayi* (Table 3.6). The peak of hyaline growth bands during spring is also not uncommon for southern African fishes and has been documented by many studies (Buxton and Clarke 1991; Bennett 1993; van Zyl 2013). This has been attributed to the food availability associated with the wind-driven upwelling events (Lutjeharms 2006), and this increase in growth results in an accumulation of daily growth increments which is observed as the annual hyaline zone deposition (Mann-Lang and Buxton 1996). Therefore, while the validation was not conclusive in this study, the assumption that *O. conwayi* deposits one hyaline and one opaque zone annually is a likely one. It is advised that due to the low proportion of samples observed in some months of this study, future studies should reassess the validation of otolith increment deposition, particularly focusing in the Western Cape, where the lowest IAPE values were observed. Alternatively, the collection of specimens by netting, injecting them with OTC and allowing them to grow out in an aquarium for a year may be an alternative approach for validating the age of *O. conwayi*.

Table 3.6: Various southern African species that occupy the same habitat as *Oplegnathus conwayi* with single opaque and hyaline depositions annually. Each species distribution and validation method has been represented with OTC (Oxytetracycline), MZA (marginal zone analysis), MIA (marginal increment analysis) all being used.

Species	Common Name	Distribution	Validation Method	Reference
Dichistius capensis	Galjoen	Southern Angola - Durban	OTC	Potts and Cowley (2005)
Umbrina robinsoni	Baardman	Western India Ocean (Cape Point - Kosi Bay)	MZA;MIA;OTC	Hutchings and Griffiths (2010)
Chrysoblephus cristiceps	Dageraad	Cape Point - Durban	MZA	Buxton (1993)
Chrysoblephus gibbiceps	Red stumpnose	Cape Point - East London	MZA	Attwood et al (2019)
Chrysoblephus lacticeps	Red roman	Cape Point - Port St Johns	OTC	Potts and Cowley (2005)
Cymatoceps nasutus	Black musselcracker	Cape Agulhas - Northern Zululand	OTC	Potts and Cowley (2005)
Diplodus capensis	Blacktail	Cape Point - Kosi Bay	MZA;OTC	Mann and Buxton (1998)
Pachymetopon blochii	Hottentot	Angola - Port Alfred	OTC	Farthing et al (2018)
Pachymetopon grande	Bronze bream	Cape Agulhas - Southern Mozambique	MZA	Buxton and Clarke (1992)

The low sample size during the months of spring may have impacted the assumption of the timing of peak spawning. During the key spawning months, samples were difficult to collect due to unfavourable sea conditions. Nevertheless, when conditions were favourable, few *O. conwayi* were observed. It is possible that this may have been related to the aggregation of fish to certain areas for spawning. Future studies should focus specifically on collecting *O. conwayi* in the months of September, October, November and December to improve current knowledge of the spawning season. To do this, sampling trips to the Wild Coast (southern Eastern Cape) may be advisable, as *O. conwayi* are highly abundant in this region. Furthermore, the identification of potential spawning sites for the species may be useful, and this may be done through the collection of FEK.

This study provided an initial step towards the collection of data necessary for species-specific management of *O. conwayi*. In the absence of a robust stock assessment, which is required before determining species-specific regulations, some of the information collected can be used to implement precautionary management regulations. The data collected in this study is sufficient for the incorporation of management measures for *O. conwayi*. The introduction of a minimum size limit of 400 mm or 1.5 kg is advised. This will allow at least 50 percent of the population the opportunity to spawn before entering into the fishery. Another finding relevant to management is that a closed season (which is normally implemented to protect species during their vulnerable spawning period (Cochrane 2002)) may not be effective for *O. conwayi*. This is due to its protracted spawning season and lack of clarity around when the peak spawning season may be. Although valuable life history data was collected in this study, information gaps such as population status, migration patterns and core distributions, among others, still need to be addressed. Following on from this, the next chapter aims to address these knowledge gaps with the aid of FEK.

CHAPTER 4

Fishers' Ecological Knowledge (FEK) to augment the understanding of the biology and stock status of *Oplegnathus conwayi*

Introduction

Understanding fishery systems holistically through an Ecosystems Approach to Fisheries (EAF) has become increasingly important in fisheries research (Paterson et al 2010, Arlinghaus et al 2017) where a socio-ecological understanding of the system is required. This approach considers the human dimension to be as equally important as the biological and ecological dimensions (Paterson et al 2010). While human dimension research has primarily focussed on socio-economic characteristics, including economic impact (Hunt and Grado 2010), behaviour (Pollnac et al 2001, Carr and Heyman 2014, Bova et al 2018) and cultural aspects (Pollnac et al 2001, Pomeroy et al 2007, Hunt and Grado 2010) of the actors in the fishery, some research has also been conducted on the interface between the natural and social sciences and humanities (Charles and Wilson 2009, Bennett et al 2017). For example, fishers have provided valuable knowledge to help management of the natural resources (Huntington et al 2004, Bradford et al 2019, Hewett 2019).

Information on the biology, population status and human dimensions of target species is imperative for managing fisheries (Garcia et al 2003). A lack of this information can negatively impact marine populations (Halpern et al 2008) due to poor management decisions and unsustainable (both economically and biologically) management practices (Pitcher 2001). While traditional life history sampling methods (see Chapter 2) provide information such as age-and-growth (mortality) and reproductive traits of a species that are required for management, they do not provide information on the stock status of the species and, as they are generally "once-off" sampling events, only represent one point in time. Long-term data on the life history and stock status of species is not only cost-prohibitive, but is frequently not available for coastal fishery species.

Fishers' Ecological Knowledge (FEK) and Local Ecological Knowledge (LEK) have become popular additions to data collection methods for managing fisheries (Hind 2015).

Fishers' Ecological Knowledge is defined as the information gained by traditional and/or local resource users (fishers) from long-term use of a specific ecosystem or fishery (Murray et al 2011; Zukowski et al 2011). Over the years, fishers build a unique knowledge of the sea and the ecosystems that they interact with (Murray et al 2011; Zukowski et al 2011). Fishers build their ecological knowledge in various ways such as handing information down through the generations, fishing groups or socialising, personal experiences targeting a specific resource, and research into the resource. This knowledge may include information on species such as their core distribution, distributional shifts, depth ranges, breeding and feeding behaviours, changes in abundance and size (Zukowski et al 2011). Although this data is often viewed as subjective (Nadasdy 2003, Gilchrist et al 2005, Shackeroff and Campbell 2007), it may be particularly useful to scientists and fisheries managers who are managing 'data-limited' species or ecosystems (Lauer and Aswani 2009, Murray et al 2011). The use of FEK has also been combined with existing fisheries information to gain an improved understanding of ecosystems (Huntington et al 2004, Gilchrist et al 2005). While the majority of FEK research has focussed on subsistence and small-scale sectors (Castello et al 2009, Gerhardinger et al 2009, Moreno-Báez et al 2010, Ainsworth 2011, Carr and Heyman 2012, Chan et al 2019), few have examined the FEK in the recreational sector. However, more recently, researchers have realised the potential of FEK in fisheries research and ichthyological studies (Sparrevohn and Storr-Paulsen 2012, Ryan et al 2013, Beaudreau and Levin 2014, Bradford et al 2019, Hewett 2019).

The collection of FEK for data-limited fisheries has other advantages, besides providing biological information and data on the status of unstudied stocks. For example, involvement in the process also tends to engender a feeling of empowerment. As fisher's knowledge is collected, they begin to feel part of the management process. This will most likely improve the perceptions on the legitimacy of the management agency and its regulations (Nielsen and Mathiesen 2003), which may result in improved levels of compliance (Nielsen and Mathiesen 2003; Nielsen 2003).

While FEK has enormous potential for use in management, the quality of the data has been questioned. In recreational fisheries, the quality of FEK can be highly variable and may depend on angler experience, skill, avidity and the importance of fishing to their lifestyle (Bryan 1977, Needham et al 2009, Gray et al 2015). These attributes have also been linked to the concept of angler specialisation (Bryan 1977), which is a framework that is used to understand behavioural diversity in recreation (Beardmore et al 2013). Here, behavioural types range from general behaviour to specialised behaviour, with specialised anglers dedicated to the activity, highly skilled and avid (Beardmore et al 2013). Using this concept, researchers have developed a range of correlated indicators (Beardmore et al 2013) that include angler preferences such as catch orientation (ie. the preference to catch one trophy fish or many small fish), centrality to lifestyle and gear type (Bryan 1977). These correlations have prompted researchers to use angler specialisation as a concept to understand diversity in fishing behaviour (Bryan 1977) and angler preferences (Beardmore et al 2013), which have provided insight on appropriate management interventions. Although several studies have suggested that specialised fishers have a greater depth of knowledge on the ecosystem (Ditton et al 1992, Morgan and Soucy 2009, Needham et al 2009), no studies have examined correlations between specialisation and FEK information. Thus, by better understanding the association between angler specialisation and FEK, researchers may be able to improve its utility for the development of fisheries knowledge and management.

Compared with other angling facets, spearfishing tends to be highly specialised due to the required diving prowess and specialised gear use. Spearfishers may also have more in-depth knowledge of the underwater world, through the observation of fishes and the ocean environment and, unlike anglers, their ecological knowledge is not necessarily limited to their target species (Pavlowich and Kapuscinski 2017). As a result, spearfishers have been used to collect a range of ecological information, including population status, age-and-growth, reproduction, migration, distribution and fish behaviour data (Mann et al 1997, Passley et al 2010, Young et al 2015, Sbragaglia et al 2018, Bradford et al 2019, Pita et al 2020). When one considers that scientific information on many fishes targeted by spearfishers is poor, it appears that the collection of FEK from this sector presents an important research gap.

Oplegnathus conwayi (Cape knifejaw) is one of South African spearfishers' top target species (Mann et al 1997, Mann and Maggs 2013). Previous publications (Chater et al 1995 and Mann et al 1997) provided basic inferences on the life history and population status of this species. These findings, when combined with those in Chapter 3, have provided information from which some management decisions can be made. However, there are still gaps in the data collected for *O. conwayi,* with some of the key research areas being the population status, the current distribution (geographically and depth) and reproductive information. Therefore, this chapter aims to use FEK to augment the understanding of the biology and population status of *O. conwayi*, compare the FEK with the traditional biological information collected in Chapter 3 and compare the FEK of specialist and non-specialist spearfishers. To achieve this, a survey was designed and disseminated both online and face-to-face at spearfishing competitions.

Materials and Methods

An online survey (google forms) was created based on previous surveys designed by Mann et al (1997), Bradford et al (2019) and Hewett (2019) (see Appendix 2). The survey was approved by the Rhodes University Human Ethical Standards Committee (No. 2019-0641-2031). Survey participants were given the option of being anonymous and gave written consent prior to partaking in the survey. The survey was divided into two components, the first questioned participants on the fish species they targeted, specifically *O. conwayi,* while the second component focused on the demographics of spearfishers themselves, including questions to determine the level of specialisation (see Appendix 2).

Spearfishers were asked to list the three main species they caught and any changes in abundance, sizes, and catches in Section one. Additionally, various questions referring specifically to biological information on *O. conwayi* were asked. These included any potential changes in abundance, size and catches of the species, as well as where the species is the most abundant, its depth range and migration, breeding months, maturity and residency. All the information collected was framed relative to where the respondent predominantly spearfished.

Section two focused on the spearfishers' demographics, and asked respondents about their age, race, sex, education, place/area of residence and where they primarily spearfished. Additional questions in this section aimed to collect information on fisher specialisation, and included the length of respondent participation in spearfishing (experience), the depths (skill) and frequency of dives (avidity), as well as whether spearfishing was a priority for them (centrality to lifestyle).

A scoring system was used to categorise the level of spearfisher specialisation. Answers from the diving depth, years of spearfishing, prioritisation of spearfishing, importance in everyday life and judgement of skills questions were used to rank spearfisher specialisation. Each question was scored from 1 to 5, and the mean rank of these gave each spearfisher a specialisation score out of 5 (5 being highly specialised). Diving depths were categorised as follows 0-5m = 1, 6-10m= 2, 11-20m = 3, 21-25m = 4, 26-35 = 5; years of diving were categorised as 0-4y = 1, 5-9y = 2 , 10-19 y = 3, 20-29y = 4 and 30y + = 5; prioritisation and importance of spearfishing scores were used from the spearfishers' survey responses. Although specialisation is generally complex, with studies identifying several different categories of specialisation (Fisher 1997), for the purposes of this study, fishers were either divided into specialists (score of four or five) or non-specialists (score of one to three). A fisher's exact test of independence (function ‘fishers. test’, [Venables and Ripley 2013] ‘CRAN’ package) was used to compare specialised and non-specialised respondents’ responses on the depth that *O. conwayi* are commonly found. Since there were differences between the responses of specialist and non-specialist spearfishers, the responses of the non-specialised respondents were removed from the dataset.

The survey was disseminated nationwide, between January 2020 and May 2020, through social media platforms such as Facebook and WhatsApp. The primary forums on Facebook included Salt Fishing South Africa, South African Underwater Fishing Federation, Huguenote Spearfishing Club and Spearfishing South Africa. The main WhatsApp groups used were spearfishing club groups such as the Border Undersea Club, Gully Jumpers, Hibiscus Spearfishing Club, Durban Undersea Club and the Huguenote Spearfishing club. Spearfishers were incentivised to participate with a small lucky draw prize for anyone who participated in the survey.

The responses were collated and divided into biogeographic regions (sub-tropical region: Northern KwaZulu-Natal – East London; warm-temperate region: East London – Cape Agulhas and the cool-temperate region: Cape Agulhas – Cape Point) (see Figure 2.1). This allocation was based on the respondent's reply to the question, “What is the closest town to your main spearfishing area?”.

All analyses were run and graphs created in R studio and R 3.6.1 (R Development Core Team). Graphs were created using the ‘ggplot2’ function. A one-way analysis of variance (ANOVA) was used with a square root transformation (given the proportional nature of the dependent variable) to compare the average proportion of catches of *O. conwayi* across the three biogeographic regions (function ‘lm’ [Fox 2020], ‘car’ package). Post-hoc analysis was done using a least-square means test for separation (function ‘lsmeans’ [Lenth 2018], adjustment ‘tukey’, ‘lsmeans’ package). Chi-squared test of independence was used to compare differences in *O. conwayi* distribution across the seven geographic regions (function ‘chisq.test’ [Ripley et al 2013], ‘MASS’ package).

Results

Demographics

A total of 103 survey responses were received from South Africa's recreational spearfishers between January 2020 and May 2020. Of the 103 surveys, one was discarded due to insufficient information. Responses were obtained from across the country, the largest proportion coming from the warm-temperate region (48%), followed by the cool-temperate region (32.4%) and finally, the sub-tropical region (19.6%) (Figure 4.1). Survey respondents varied in age from 18 to over 60, were predominantly white (97.1%) and all were male. Ninety percent of the respondents had tertiary education and 79.4% of them were employed, while the remainder were students (10.8%) and retirees (5.9%). The majority (71.6%) of respondents were not affiliated with the South African Underwater Fishing Federation (SAUFF).

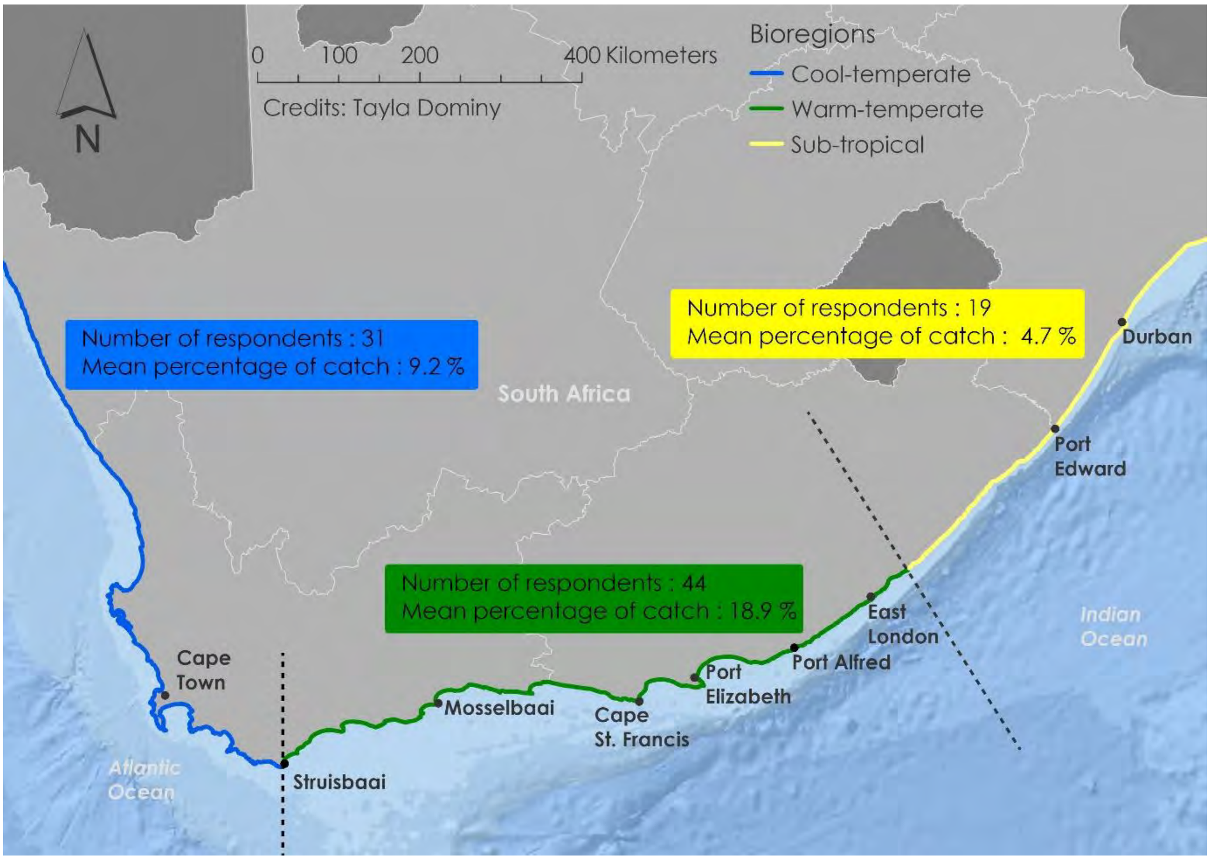

Figure 4.1: Map of South Africa indicating the number of respondents from each of the three biogeographic zones and the mean percentage of catches of *Oplegnathus conwayi* by spearfishers in their respective regions.

Spearfisher specialisation

The average specialised respondent had 19.7 years (SD ±13.7, range 1-53) of diving experience, with the majority of respondents (74.5%) being able to dive to 20 m and 58.2% rating themselves to have higher skills than the average spearfisher (Table 4.1). The average non-specialised respondent had 4.3 years (SD ±2.4, range 1-8) of diving experience, with 37% able to dive to 20 m and 25% rating their skills higher than the average spearfisher (Table 4.1). Both specialised and non-specialised respondents tended to target larger but fewer fish, rather than multiple small fish (Table 4.1). Shore diving and boat diving were equally popular among the participants, with specialised respondents choosing to primarily boat dive compared to non-specialised respondents who chose to shore-dive. Spearfishing appeared to be central to respondents' lives (80.4% of respondents said it had a significant influence on their lives) and 83.3% prioritised this activity over all other recreational activities (Table 4.1). Based on the methodology described above, 94 (92.2%) respondents could be categorised as specialists. Of these, 39 (38.2%) could be categorised as highly specialised (rank 5) and 55 (53.9%) as specialised (rank 4). The remaining 8 (7.8%) were categorised as unspecialised (rank 1-3).

Comparisons between specialist and non-specialist FEK

The target species for specialists and non-specialists were similar, with specialists primarily catching *Seriola lalandi, Pachymetopon grande, O. conwayi* and *Sparodon durbanensis* and non-specialists *S. lalandi, O. conwayi, P. blochii* and *S. durbanensis* (Table 4.1). Respondents' opinions on where *O. conwayi* are most commonly found were variable. Specialists gave a wide range of responses, many of which differed depending on primary spearfishing region. In contrast, non-specialised respondents indicated *O. conwayi* were most commonly found in their main spearfishing region. Specialised and non-specialised respondents had similar (Fishers test, $p \geq 0.05$) answers pertaining to the depth at which both large and juvenile *O. conwayi* are found, with specialised respondents indicating that larger *O. conwayi* are found slightly deeper (Table 4.1). When questioned on the reproduction (breeding months and observations of spawning) of *O. conwayi*, a small percentage of specialised respondents (23.4%) could provide an answer, however, not a single non-specialised respondent answered. Both specialised and non-specialised respondents did, however, indicated a similar size of sexual maturity for *O. conwayi*. When questioned about changes in depths of *O. conwayi* throughout the year, a larger proportion of specialised respondents had observed changes compared to non-specialised respondents. The few non-specialised respondents who did observe this were from the cool-temperate region. Overall, the majority of specialists felt that there had been no change in the abundance (43.8%), size (53%) and catch (55.1%) of *O. conwayi* over the years they had been spearfishing (Figure 4.2, Table 4.1). By contrast, almost all non-specialists felt that there had been no change in the abundance (85.7%), size (100%) and catch (85.7%) of *O. conwayi* over the time they had been spearfishing (Table 4.1). Based on the lack of experience observed for non-specialised respondents, the differences observed between the specialised and non-specialised respondents, the additional detail observed in specialised respondents' surveys, and the lack of response to some questions by non-specialised respondents (Table 4.1), the data for the remainder of the results section was based on specialised respondents' responses only.

Table 4.1: A summary of the main results from the survey comparing specialised and non-specialised respondents.

	Specialised	**Non-specialised**
Number of respondents	94	8
Top 4 frequently targeted species by respondents	*Seriola lalandi; Pachymetopon grande; Oplegnathus conwayi; Sparodon durbanensis*	*Seriola lalandi; Oplegnathus conwayi; Pachymetopon blochii; Sparodon durbanensis*
Percentage of overall catch that *O. conwayi* comprised of for respondents	12.9	14.8
Respondent opinions on where *O. conwayi* are most common	Extremely varied (see Figure 4.4)	All answers were based around where they spearfished most often (showing very little experience diving elsewhere)
Most common depth range large *O. conwayi* were commonly found at by respondents	11-15m (deepest recording of 40m)	6-10m (deepest recording of 15m)
Most common depth range juvenile *O. conwayi* were commonly found at by respondents	6-10m	6-10m
The main time of the year the smallest *O. conwayi* individuals were observed by respondents	23.4% answered: December January and February being the main months	Unanswered
When the breeding months of *O. conwayi* are, based on respondents' opinions	27.7% answered: November, December and January having the majority of responses	Unanswered
The average of respondents' opinions on the length of mature *O. conwayi* (cm)	30-35cm	30-35cm
The number of respondents who had observed a spawning event or aggregation of *O. conwayi*	7	0
Percentage of respondents who noticed a change in depth for *O. conwayi* during certain times of the year	85.1%	50%
Responses regarding the changes in abundance of *O. conwayi* during respondents' years of spearfishing	The majority answered no change (See Figure 4.2 for more detail)	All bar one respondent answered, no change
Responses regarding the changes in size of *O. conwayi* during respondents' years of spearfishing	The majority answered no change (See Figure 4.2 for more detail)	All answered No change
Responses regarding the changes in catches of *O. conwayi* during respondents' years of spearfishing	The majority answered no change (See Figure 4.2 for more detail)	All bar one respondent answered, no change
Average diving experience (years)	19.7	4.3
Average monthly spearfishing outings	3-5	0-2
Average respondents' prioritisation of spearfishing	Mostly - always spearfishing (4-5)	Often - mostly spearfishing (3-4)
Average respondents' centrality to lifestyle	Extremely important (4-5)	Average - relatively important (3-4)
Judgement of overall skills compared to other spearfishers	Medium - high skills (3-4)	Low - medium skills (2-3)
Choice of shooting fewer large fish or many small fish?	Fewer larger fish	Fewer larger fish
Average maximum diving depth	22.8m (maximum 40m+)	15m (maximum 20m)
Number of SAUFF affiliations	29	0
Most common primary means of spearfishing	Boat diving	Shore-diving

Spearfisher perceptions on the population demography of the species most commonly caught

A total of 31 different species were recorded as the primary species caught by respondents' (Table 4.2). These ranged from pelagic tropical fishes such as *Scomberomorus commerson*, *Coryphaena hippurus* and *Acanthocybium solandri*, to benthic fishes such as *S. durbanensis*, *Pachymetopon aeneum* and *P. grande*. The primary species caught by respondents were *S. lalandi* (13.9%) followed by *P. grande* (11.7%), *O. conwayi* (11.4%) and *S. durbanensis* (11%) (Figure 4.2). Overall, respondents had similar responses to the changes in abundance, size and catches of the 31 different species, with the largest proportion of responses suggesting there have been no changes in abundance (50.7%), size (57.1%) and catches (53.2%), over the years the respondents have been spearfishing.

In terms of the species most commonly shot, the majority of respondents (65.8%) indicated that the abundance of *S. lalandi* has remained unchanged, while 21.1% and 13.1% felt that it had slightly decreased and slightly increased, respectively (Figure 4.2a). A total of 78.9 % of the respondents felt that the average size of *S. lalandi* had not changed, while only 15.8% and 5.3% suggested that there was a slight decrease and increase in size, respectively (Figure 4.2a). The majority of respondents (52.6%) perceived no change in catches of *S. lalandi*, while 31.6% and 15.8% suggested there had been a decrease and increase in the catch, respectively (Figure 4.2a).

A total of 53.1% of the respondents indicated that the abundance of *P. grande* had not changed, while around one third (34.4%) suggested a slight decrease and 12.5% a slight increase (Figure 4.2b). A large proportion (59.4%) of respondents indicated that the size of *P. grande* has remained the same, while around one third (34.4%) indicated a decrease in size, and the remainder (6.2%) suggested an increase (Figure 4.2b). Fifty-three percent of the respondents indicated that catches of *P. grande* have remained the same, while 37.5% and 9.4% had indicated a decrease and increase in catches, respectively (Figure 4.2b).

Almost half (43.8%) of the respondents thought that the abundance of *O. conwayi* has not changed in their primary spearfishing region, while a similar proportion (44.8%) indicated there has been a decrease. Only 11.2% suggested an increase in abundance (Figure 4.2c). Fifty-three percent of respondents felt that the size of *O. conwayi* has not changed, while 39.4% and 7.9% indicated that the sizes have decreased and increased, respectively, in their spearfishing region (Figure 4.2c). A total of 55.1% of the respondents thought that catches of *O. conwayi* had not changed, while 37.1% and 7.9% of the respondents indicated that catches had decreased and increased, respectively (Figure 4.2c).

Approximately half (46.7%) of the respondents indicated that the abundance of *S. durbanensis* has not changed, similarly, 46.7% suggested there has been a decrease, while 6.7% indicated an increase (Figure 4.2d). Fifty-three percent of respondents felt the size of *S. durbanensis* has not changed over the years they have been fishing, whilst 43.4% indicated a decrease, and a mere 3.3% indicated an increase (Figure 4.2d). A total of 66.7% of the respondents thought that catches of *S. durbanensis* have remained the same in the time they have been spearfishing, whilst only 23.3% and 10% indicated they have decreased and increased, respectively (Figure 4.2d).

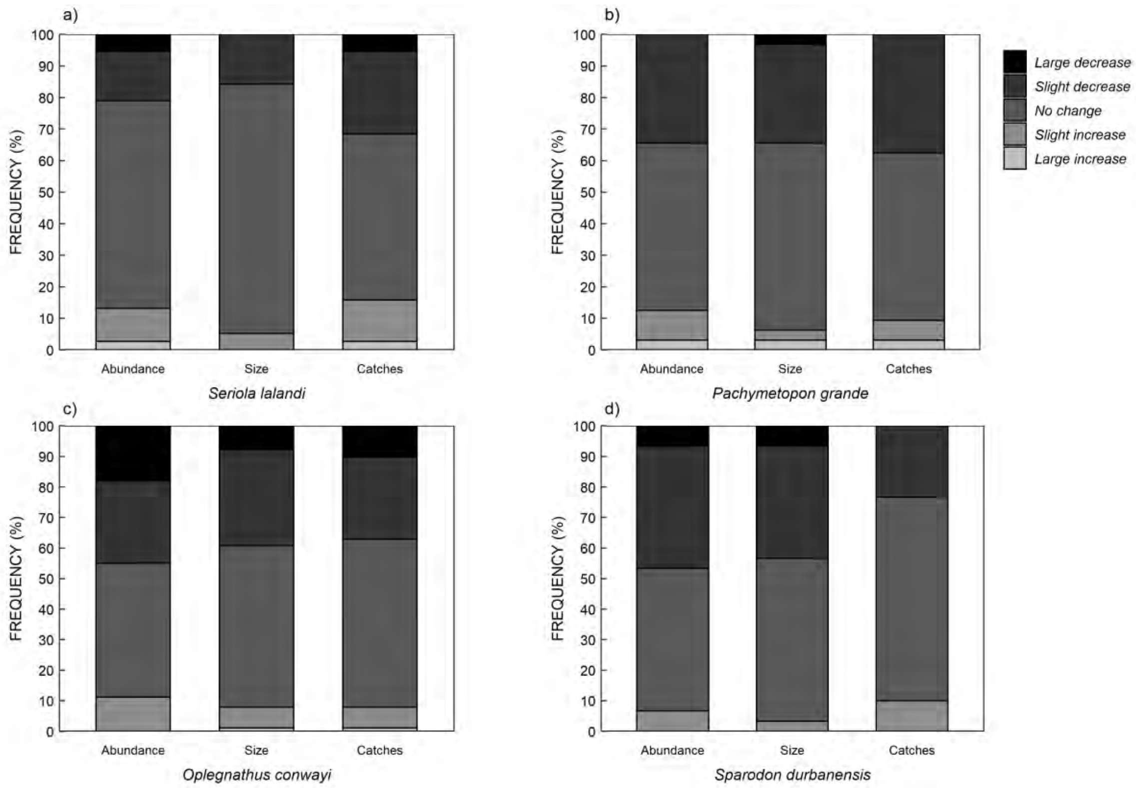

Figure 4.2: The perceived change in abundance, size and catches of the four most commonly caught species (a) *Seriola lalandi*, (b) *Pachymetopon grande,* (c) *Oplegnathus conwayi* and (d) *Sparodon durbanensis* by South African spearfishers from 103 surveys.

Table 4.2: List of the main target species of South Africa spearfishers, as indicated by the survey. Data collected from and Mann (2013). International Union for Conservation (IUCN) listings: EN (endangered), VU (vulnerable), NT (near threatened), LC (least concern), and DD (data deficient). Harvesting methods: R (rod and line), S (spearfishing), R/S (both rod and line and spearfishing). Biogeographic regions: ST (sub-tropical), WT (warm-temperate) and CT (cool-temperate).

Family	Species	Common Name	IUCN Listing	Size at Maturity (mm)	Legal size limit (mm)	Legal bag limit	Harvesting method	Biogeographic region
Carangidae	*Lichia amia*	Leerie (Garrick)	LC	800	700	2	R/S	All
	Seriola lalandi	Cape yellowtail	LC	470 -834	Unknown	10	R/S	All
	Seriola rivoliana	Tropical yellowtail	LC	Unknown	Unknown	10	R/S	ST
Cheilodactylidae	*Chirodactylus brachydactylus*	Butterfish (twotone fingerfin)	Unknown	Unknown	Unknown	10	S	WT;CT
	Chirodactylus grandis	Grey banksteenbras	DD	Unknown	Unknown	5	S	WT;CT
	Chirodactylus jessicalenorum	Natal banksteenbras	DD	Unknown	Unknown	5	S	ST;WT
Coryphaenidae	*Coryphaena hippurus*	Dorado	LC	700-800	Unknown	10	R/S	ST
Dichistiidae	*Dichistius capensis*	Galjoen	Unknown	310-341	350	2	R/S	WT;CT
Haemulidae	*Plectorhinchus chubbi*	Dusky rubberlips	DD	Unknown	Unknown	10	R/S	ST
Oplegnathidae	*Oplegnathus conwayi*	Cape knifejaw	Unknown		Unknown	5	S	All
Parascorpididae	*Parascorpis typus*	Jutjaw	Unknown	Unknown	Unknown	10	S	WT;CT
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	EN	920-1071	601 or 400(boats)	2 or 5 (boat)	R/S	All
	Argyrosomus thorpei	Squaretail kob	EN	900	600	2	R/S	ST
	Umbrina robinsoni	Bardman	DD	370-480	400	5	R/S	All
Scombridae	*Acanthocybium solandri*	Wahoo	LC	932-1020	Unknown	10	R/S	ST
	Sarda sarda	Atlantic bonito	LC	Unknown	Unknown	10	R/S	WT;CT
	Scomberomorus commerson	King mackerel (couta)	NT	677	Unknown	10	R/S	ST
	Scomberomorus plurilineatus	Queen mackerel (Natal snoek)	DD	750	Unknown	10	R/S	ST
	Thunnus alalunga	Longfin tuna	NT	900	Unknown	10	R/S	ST;CT
Serranidae	*Epinephelus andersoni*	Catface rockcod	NT	430-500	500	5	R/S	ST;WT
Sparidae	*Chrysoblephus anglicus*	Englishman	NT	400	400	2	R/S	ST;WT
	Chrysoblephus gibbiceps	Red stumpnose	EN	210-250	300	1	R/S	WT;CT
	Chrysoblephus lacticeps	Red roman	Unknown	180	300	2	R/S	WT;CT
	Cymatoceps nasutus	Black musselcracker	VU	530	500	1	R/S	All
	Diplodus capensis	Blacktail	LC	150-160	200	5	R/S	All
	Gymnocrotaphus curvidens	John brown	LC	Unknown	Unknown	5	R/S	WT;CT
	Lithognathus lithognathus	White steenbras	EN	650	600	1	R/S	All
	Polyamblyodon germanum	German bream	Unknown	Unknown	Unknown	10	R/S	ST;WT
	Pachymetopon blochii	Hottentot	LC	200-220	220	10	R/S	WT;CT
	Pachymetopon grande	Bronze bream	NT	300	300	2	R/S	ST;WT
	Sparodon durbanensis	White musselcracker	NT	350	600	2	R/S	All

Spearfishers knowledge of *Oplegnathus conwayi*

Oplegnathus conwayi was the most caught species for only eight (8.5%) of the 94 specialist respondents. Nine respondents indicated that it was their second most commonly caught species and 17 suggested that it was their third most caught species. On average, *O. conwayi* made up 12.9% of the catch of spearfishers across the country. In contrast to the catch, 64.9% of respondents indicated that they often (most dive days) saw *O. conwayi*, while 20.2% indicated that they saw them occasionally (every second dive day) and 14.8% said that they seldom (few dive days in a year) saw them (Figure 4.3a). About a third (32.9%) of respondents indicated that they often spear *O. conwayi* and another third (30.9%) indicated that they spear them occasionally, while 36.2% indicated that they seldom or never spear the species (Figure 4.3b).

When divided by biogeographic region, *O. conwayi* made up 18.9% of the catch of spearfishers in the warm-temperate region, which was significantly higher compared to the cool-temperate (9.2%) and sub-tropical zones (4.7%), ($F[2, 101] = 15.8$, $p < 0.01$) (Figure 4.1). A large proportion (65.9%) of respondents from the warm-temperate areas indicated that *O. conwayi* are abundant, with most (90.9%) of the respondents often seeing *O. conwayi,* but only half (50%) often speared them (Table 4.3). Respondents from the cool-temperate region indicated that *O. conwayi* made up 9.2% of their catch. Respondents in this region indicated that *O. conwayi* are not highly abundant, with 64.6% of respondents often seeing *O. conwayi*, while only 19.4% often speared them (Table 4.3). *Oplegnathus conwayi* made up very little (4.7%) of respondents' catches in the sub-tropical region. Respondents indicated that the abundance of the species was very low in this region, with 42.1% of respondents occasionally observing them and 36.9% seldom observed them (Table 4.3). A total of 63.2% of the respondents did not actively target *O. conwayi* in this region (42.1% seldom and 21.1% never).

Table 4.3: Perceptions of the spearfishing respondents on the abundance of *Oplegnathus conwayi* in their respective spearfishing bioregions.

	Highly Abundant	Abundant	Moderate Abundance	Low Abundance	Scarce
Warm-temperate	31.82%	34.09%	25.0%	9.09%	0.0%
Cool-temperate	12.9%	22.58%	25.81%	19.36%	19.35%
Sub-tropical	0.0%	10.53%	5.26%	42.12%	42.11%

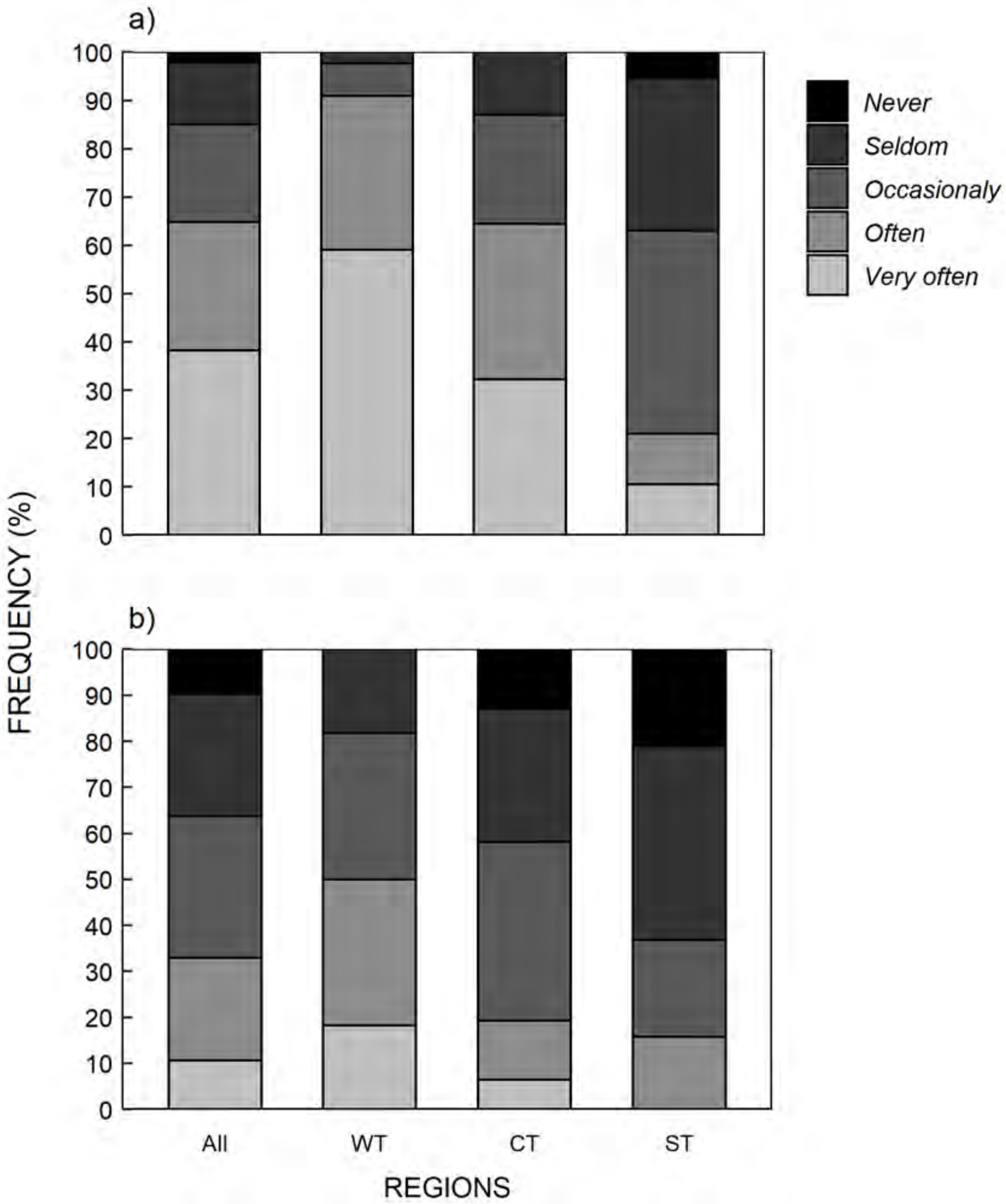

Figure 4.3: The frequency of responses to the relative amount of *Oplegnathus conwayi* that are a) seen and b) speared, over all the biogeographic regions and in each separate region of South Africa.

Respondents indicated that *O. conwayi* were relatively evenly distributed across the seven geographic regions (χ^2 (12) = 32.4, p = 0.001), with the largest proportion (29.8%) showing that they are most common along the Transkei (Figure 4.4). Additionally, 46.8% of respondents replied that the largest *O. conwayi* were also found along the Transkei coast, while the remainder indicated that the largest *O. conwayi* were spread across all the other geographic regions (Figure 4.4). The largest proportion of respondents (20.2%) indicated that juvenile *O. conwayi* are found in the Transkei and are evenly distributed (19.9%), respectively, followed by their presence in the Border (6.9%) region and KwaZulu-Natal (5.9%).

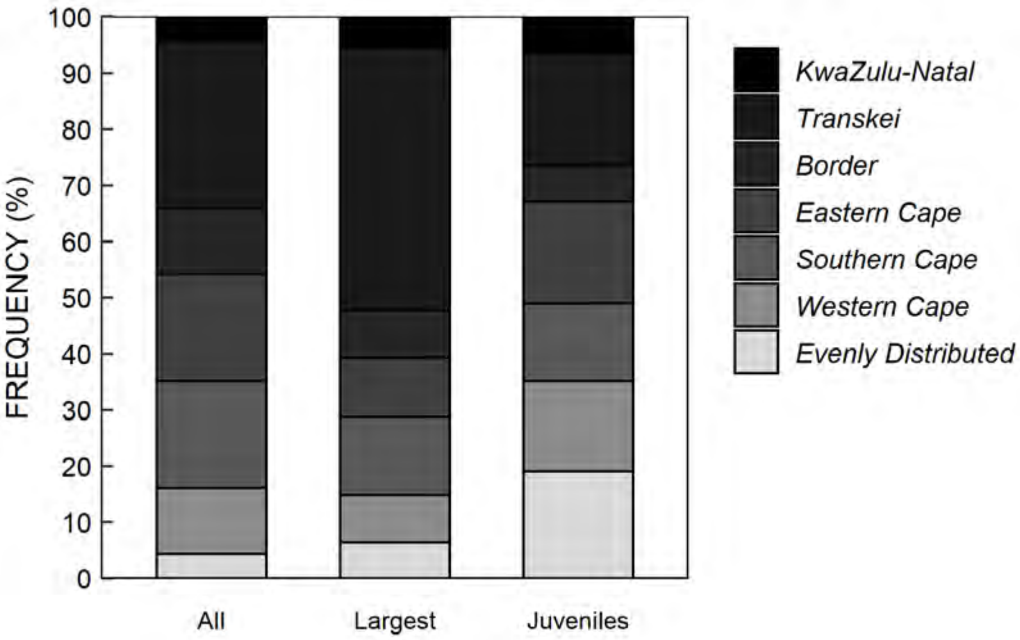

Figure 4.4: Spearfishers perceptions of where all, the largest and juvenile *Oplegnathus conwayi* are distributed along the South Africa coastline, respectively. KwaZulu Natal (Kosi Bay – Port Edward), Transkei (Port Edward – Kei Mouth), Border (Kei Mouth – Hamburg), Eastern Cape – (Hamburg – Cape St Francis), Southern Cape (Cape St Francis – Mossel bay), Western Cape (Mossel bay – Cape Point), see Appendix 2.

In terms of depth, half (48.9%) of the respondents indicated that *O. conwayi* were primarily found at depths between 11 and 15 m (Figure 4.5). Only 2.2% replied that *O. conwayi* were located in depths of up to 40 m. Forty-six percent of respondents indicated that juveniles were found at depths between six and 10 m, with a maximum depth of between 21 and 25 m (Figure 4.5). A large percentage of the respondents (85.1%) thought that *O. conwayi* did not migrate to deeper waters during the year. Of those (14.9%) who did feel that there was a migration, two-thirds indicated that *O. conwayi* were found deeper during winter (May-August). Most respondents (63.8%) indicated that *O. conwayi* are commonly shot all year round, while the other 23.2% thought that they are mostly shot in the summer months (September – March). Fifty-six percent of the respondents indicated that *O. conwayi* were resident and remained on the same reef all year, while 34% thought that only some individuals were resident, and 9.6% indicated they were migratory.

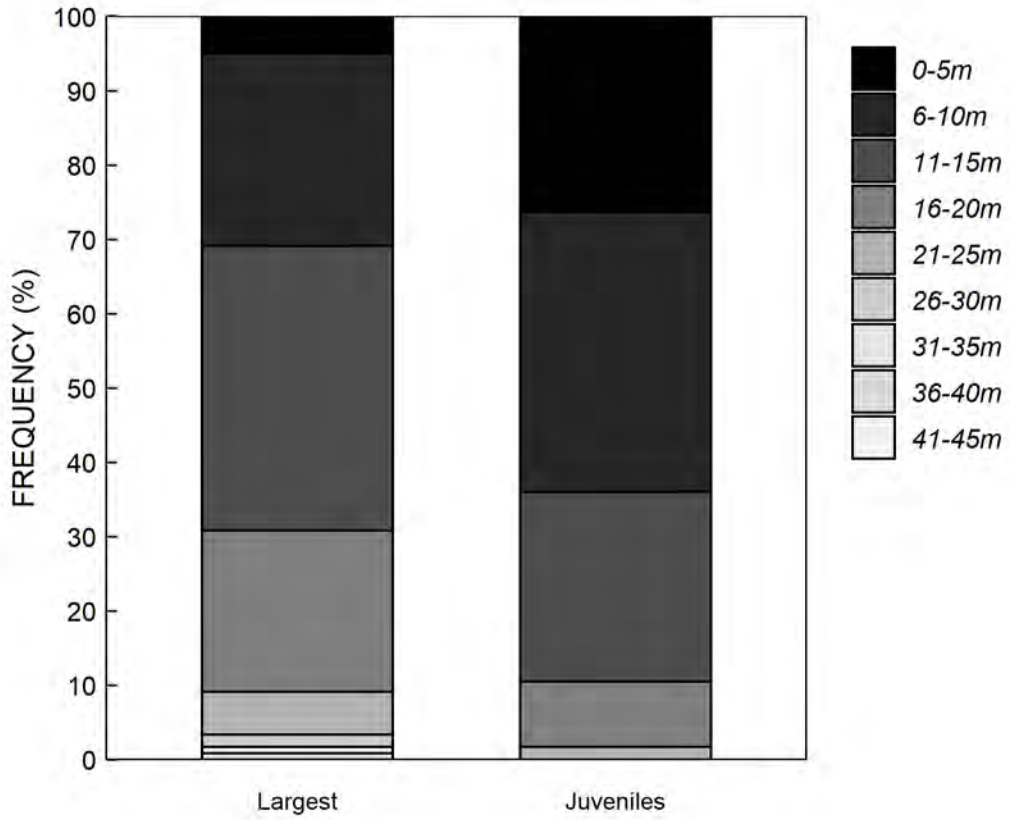

Figure 4.5: The relative frequency of depths that both large and juvenile *Oplegnathus conwayi* are found on the South African east and south coastlines, according to respondents.

The majority of respondents (72.3%) did not know the peak spawning months of *O. conwayi.* Similarly, most (76.6%) respondents did not know in which months of the year the smallest individuals were seen. The respondents (23.4%) who did provide an answer to these two questions, indicated that the species spawns in every month of the year with the majority indicating that spawning occurs in November (6.4%), December (10.6%) and January (7.4%) (Figure 4.6). Respondents estimated a mean length-at-maturity of 331.3 mm and a mean weight of 1.64 kg. Only seven of the 102 respondents (three from the warm-temperate region, two from the sub-tropical region and two from the cool-temperate region) indicated that they had actively seen *O. conwayi* spawning. Although each account was slightly different, overall, the remarks from the respondents suggested that *O. conwayi* form aggregations and spawn in the water column. Some (n = 4) suggested that fish spawned in pairs within the aggregations. One respondent from northern KwaZulu-Natal suggested that large spawning aggregations that used to be prevalent in the area, had not been observed in the last five years.

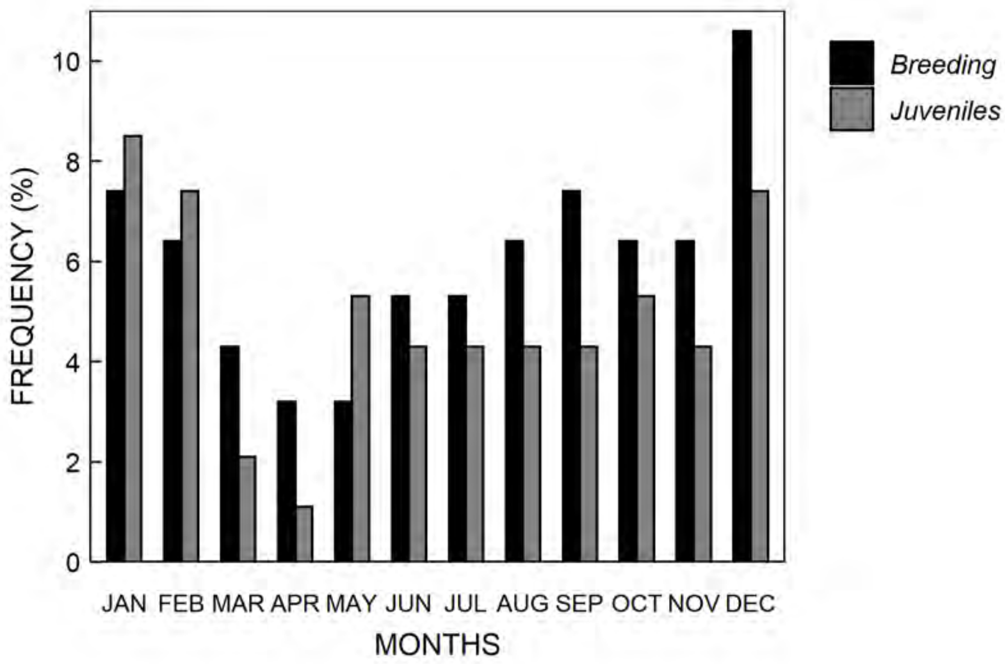

Figure 4.6: The relative frequency of the perceived breeding months for *Oplegnathus conwayi* and months when the largest proportion of juvenile *Oplegnathus conwayi* are found on the South African coast, according to respondents.

Discussion

The FEK for *O. conwayi* not only supported the findings from the traditional biological study (Chapter 3), but also provided valuable insights on other aspects of their life history, such as spawning behaviour, and on the status of the *O. conwayi* population. Key life history information included further support for a year-round reproductive season, with a peak in late spring/early summer. The average length-at-50% maturity from Chapter 3 (350.7 mm; SD 18.39) and the length indicated by respondents was also similar. Additionally, this study's results filled key data gaps for *O. conwayi* such as the core distribution, depth migration and limits, movement behaviour, key depth ranges, and further validated the importance of *O. conwayi* in the South African spearfishery. While valuable fisheries management data was collected for *O. conwayi*, the use of specialised FEK data proved to be of great importance in this study, as specialised respondents appeared not only to have more detailed FEK, but differences in the information presented were also observed when compared to the non-specialists.

Since the subjective nature of FEK has the potential to provide inaccurate data and misleading results, it is imperative to obtain/acquire the most accurate FEK data (Shackeroff and Campbell 2007). Based on the results of this Chapter, it appears that the resolution of FEK data can be improved through the use of specialist fishers. Several other studies (Chalmers and Fabricus 2007, Needham et al 2009, Gray et al 2015) have also drawn this conclusion, however, none of these examined the value of FEK in a recreational spearfishery. Because of the sampling method, the participants in this study can be considered specialists compared to the average recreational spearfisher. Despite this, it was apparent that the ecological knowledge, including fish distributions (both depth and geographical), reproductive information and population changes information was different between the specialists and non-specialists (Table 4.1). Specialist spearfishermen also tended to provide additional in-depth information, such as observations of spawning behaviour, no doubt due to their extensive experience in the underwater environment compared to the non-specialists. Although still preliminary, these findings suggest that recreational specialisation may provide a useful concept to improve the accuracy of FEK data in recreational fisheries and should be included in future research.

The majority of spearfishers suggested that there had been no changes in the abundance, size and catch of the 31 species commonly caught. Although this pattern was similar for *O. conwayi*, a proportion of respondents indicated a decrease in the abundance, size and catches when compared to the perceptions about the other three main species that are caught (Figure 4.2). While there is no historical information on the population status of *O. conwayi,* the population status of *S. durbanensis,* which had similar responses to *O. conwayi* in this survey, is considered to be declining (Griffiths and Lamberth 2002, Hewett 2019). Thus, this study's findings may provide some evidence to suggest that the population of *O. conwayi* may be declining.

Oplegnathus conwayi constitute a large and important proportion of the catch of South African spearfishers. Although not the first and most commonly caught species, *O. conwayi* were in the top four most commonly caught species for respondents from this study. Similarly, Mann et al (1997) indicated that *O. conwayi* were the sixth main target species for spearfishers in the Western and Eastern Cape. The increase of importance in catches of *O. conwayi* from sixth in 1997 to fourth in 2020, could be attributed to a general decline in other target species (Table 3.5) (Griffiths 2000). A large proportion of spearfishers' main target species are currently overexploited, with pressure from multiple coastal fishery sectors (Table 3.5) (Griffiths 2000). The extensive pressure and overfishing have led to declines in other target species, resulting in a shift towards targeting *O. conwayi*. Catches of *O. conwayi* were highest for respondents in the warm- and cool-temperate regions, with very little importance ascribed to, and low catch rates reported, in the sub-tropical region. This was in agreement with Mann et al (1997), who indicated that *O. conwayi* made up a large proportion of spearfishers' catch in Western Cape and Eastern Cape but were of little importance in Kwa-Zulu Natal. These findings suggest that the *O. conwayi* may require some type/manner of protection from overexploitation, especially along the Eastern Cape and Western Cape coasts.

The cumulative impacts of exploitation and climate change have become more pronounced in the Anthropocene, and have resulted in local depletions (Engelhard et al 2014, Hollowed et al 2013) and shifts in the distribution (Lloyd et al 2012, Engelhard et al 2014, Hollowed et al 2013, Poloczanska et al 2013) of many fish populations. In terms of *O. conwayi*, local depletions as a result of exploitation are more likely to occur in the sub-tropical and cool-temperate zones, where the species is less abundant. Fortunately, the indication of low abundance and catch rates in the sub-tropical region has not changed when compared with the findings of Mann et al (1997). This suggests that there has not been a decline in the population in the sub-tropical region, and no distributional shifts have occurred. While this is currently the case, climate signals will most likely occur in areas experiencing rapid change. The strengthening of the Agulhas Current and warming conditions in the sub-tropical region (Potts et al 2015) may impact the distribution of *O. conwayi* in this region. Indeed, Lloyd et al (2012) examined climate-induced changes on a sub-tropical fish assemblage using spearfishing data from Kwa-Zulu Natal and, although they did not find evidence for poleward distributional shifts of temperate species, they found evidence of increases in the abundance of tropical species.

The higher catch rates in the Western Cape and Eastern Cape when compared with Kwa-Zulu Natal (Mann et al 1997), provides evidence of the higher abundance of *O. conwayi* in the warm- and cool-temperate regions in this study. Although abundant and an important target species in the warm-temperate region, respondents indicated that the Transkei, which falls in the sub-tropical region, has the greatest abundance of both large and juvenile *O. conwayi*. However, the Transkei is an extremely remote location with very few local recreational spearfishers. The lack of participants in this study from this region further supported the low numbers of recreational spearfishers in this remote location. Thus, the data for the sub-tropical region could be skewed, and inferences made on the sub-tropical region may only indicate what is being observed in Kwa-Zulu Natal. Conversely, the lack of spearfishing pressure in the Transkei may explain the perceptions of high abundance in this region. However, the results from this study and Mann et al (1997) still suggest that *O. conwayi* have a core region and are most abundant in the Eastern Cape of South Africa. Based on the perceptions of the respondents (Figure 4.2), there appeared to be little evidence of population declines of warm-temperate species and, specifically, *O. conwayi*. This suggests that the population is currently stable in all the regions along the South African coastline and that this species may be resilient to the environmental changes associated with climate change.

Little is known about the depth range of *O. conwayi,* although a maximum depth reported for the species was 32 m (Heemstra and Heemstra 2004). Respondents from this study suggested *O. conwayi* are commonly found in the 11 to 15m depth range with the juveniles found slightly shallower. Only two respondents indicated they have seen *O. conwayi* at depths of 40m, as this depth is not commonly achieved due to spearfishers physical limitations, this finding is not unsurprising. The lack of evidence for an abundance of fish in deep water (30-40m) suggests that depth may not provide *O. conwayi* with refuge from exploitation as suggested by Chater et al (1995). This is concerning, as the majority of respondents who completed this survey are able to access these fish throughout their depth distribution.

Oplegnathus conwayi are also thought to be resident with territorial behaviour (van der Elst 1993). While the majority of respondents supported van der Elst's (1993) proposal that *O. conwayi* are resident, 34% suggested that some individuals may be resident while others migrate. These migrations were not thought to be longshore, but rather these fish were thought to migrate to deeper waters in winter. Mcilwain et al (2011) found that monsoon- generated upwelling events in the Gulf of Oman caused demersal fish to congregate in shallower depths during summer. It is possible that east wind-driven cold-water upwelling events observed in the summer months of South Africa may also drive a shallow water migration. Indeed, Hanekom et al (1989) documented the inshore movement of coastal fishes during intense upwelling events, with some entering the estuarine environment.

Questions regarding spawning and reproductive seasonality were predominantly left unanswered, with respondents indicating they had little knowledge on the spawning of *O. conwayi*. The respondents (all of whom were specialised) who did answer, however, suggested that *O. conwayi* spawn year-round, with a peak being seen in November, December and January. Spawning aggregations could be a reason for the general lack of specimens and difficulty in finding *O. conwayi* during the sampling period in October and November (see Chapter 3). This does, however, need to be further explored in future studies. The reports of year-round spawning align well with the results of the traditional biological sampling (Chapter 3, Chater et al (1995)).

In terms of spawning behaviour, seven respondents (all of whom were specialised) reported aggregations and spawning behaviour for *O. conwayi*. These respondents were from all three biogeographic regions, suggesting that spawning occurs throughout the South African coastline. These respondents also indicated that *O. conwayi* spawn in pairs within aggregations. These reports correspond with van der Elst's (1993) suggestion that the species is territorial in nature and form pair bonds.

A total of 103 survey responses were received from South African spearfishers, which is low compared to the estimated 33 616 participants in the spearfishery in 2017 (Saayman et al 2017). This low sample size could be attributed to two factors, the first being that Saayman's figure represented above is not a true representation of active spearfishers in South Africa who could confidently answer the survey. Secondly, the survey distribution method (Online) may have prevented spearfishers who do not actively use social media platforms from finding out about the survey. Future studies should investigate using the South African licencing system to email surveys to all spearfishers who purchased a licence. Additionally, although this may be cost prohibitive, face-to-face interviews or roving creel surveys could be considered to provide information from spearfishers who do not actively use technology. The final limitation for studies such as these is the capability of the spearfishers, where their knowledge of a species is limited to the depths and time, they spend diving. For example, nocturnal aggregations may go unnoticed, or the true maximum depth of a species may be unknown due to divers not reaching that depth. The use of Baited Remote Underwater Video (BRUV) systems may be used as an alternative method for collecting this information, particularly for species that can not be targeted on hook and line.

Collecting FEK data on the South African spearfishery and *O. conwayi* proved to be successful, with valuable ecological, biological, and spatio-temporal distribution data gathered. Results from this study could contribute to knowledge required to implement some precautionary management regulations for the species e.g. the introduction of a minimum size limit of 400 mm or 1.5 kgs, and reducing the total allowable daily catch from five to two per person. It is, however, advisable to support this information with traditional biological data and stock assessments, where possible. The use of spearfisher FEK may have great potential for the collection of information on data-limited species in South Africa, although the findings of this study have suggested that efforts should be made to incorporate the concept of specialisation to maximise the value of this data. Incorporating FEK into data collection frameworks for management will also promote stakeholder involvement in research, which may promote perceptions of legitimacy (Nielsen and Mathiesen 2003; Nielsen 2003, Gourguet et al 2018, Pita et al 2018). This, as is discussed in the next chapter (Chapter 5), will improve the management of the complex socio-ecological system that is the South African coastal fishery.

CHAPTER 5

General Discussion

The implementation of the social-ecological system's (SES) approach to managing fisheries has become widespread, with many fisheries scientists strongly recommending it (Ostrom 2009, Butler 2019). The greatest value of the SES approach is the improved holistic understanding of fisheries and how to manage them (Ostrom 2009, Butler 2019). This thesis aimed to incorporate a SES approach to improve current understanding of aspects of the South African recreational spearfishery through the collection of biological information on *O. conwayi* and human dimension information on the spearfishery. These insights provided valuable information to improve the understanding, not only of the spearfishery, but also in the context of the hugely complex coastal fisheries SES in South Africa (Potts et al 2020a).

Based on Ostrom's (2007, 2009) general framework for analysing the sustainability of SES's, three core sub-systems were identified, and information was obtained to contribute to each of them. These were the ecosystem (resource system and resource units) (Chapters 2 and 3), the social system (resource users and groups involved, Chapter 4) and the governance system (Chapters 1 and 5) (Figure 5.1). The linkages between these systems and external influencing factors were also discussed. The potential utility of the data collected to promote a resilient SES will be discussed in this chapter. Finally, the implementation of this approach to gain a better, more holistic understanding of recreational fisheries in developing countries will be discussed.

An in-depth understanding of the biology of a species has always been a critical step in managing a species, particularly in traditional fisheries management (King and McFarlane 2003). However, this information is equally important in SES's where an understanding of the ecosystem and resource is imperative (Ostrom et al 1994, Arlinghaus 2017, Butler 2019). Biological traits such as age-and-growth and reproduction are perhaps the most critical, as they can be incorporated into stock assessment and can be used to design appropriate species-specific regulations (King and McFarlane 2003; Winemiller 2005; Young et al 2006). In terms of these traits, *O. conwayi* are slow growing, long-lived, late maturing and exhibited an extended spawning season with a peak in spring (September, October, November) (Chapter 3). Slow growth and late maturation are common traits of species that are susceptible to overexploitation, if they are not managed appropriately. Conversely, fish with extended spawning seasons are less susceptible than those that have a distinct spawning season and form large and predictable aggregations (Coleman et al 2011, de Mitcheson 2016).

While initial indications in both Chapters 3 and 4 provided evidence for an extended spawning season, the low sample sizes (Chapter 3) during spring may have precluded the identification of a peak spawning period. It is possible that the lack of specimens during these months may be due to the aggregation of fish in unsampled areas. The FEK certainly suggested that aggregations occurred during spring, and that these are difficult to locate, as indicated by the low number of individuals who managed to observe these. This may confer some resilience to this population, but if the aggregations are found and predictably located, it is possible that the species could rapidly be overexploited. Future research should therefore aim to better understand the spawning season and behaviour of this species and managers should ensure that this information is incorporated into management strategies.

The poor sample size in October and November also influenced the validation of growth zone deposition. While poor accuracy of ageing measurements may have a considerable impact on estimated growth and stock assessments, the assumption of the deposition of one ring per year appears to hold for South African coastal fishes (Table 3.6), and is therefore the most likely scenario. Nevertheless, future studies should aim to improve the sample sizes in spring and incorporate alternative methods (eg. chemical marking and captive holding) to confirm the age validation.

With the development of SES's, data collection methods have adapted and changed (Garcia et al 2003). One of the key inclusions, and a developing field of study, is the addition of Fishers' Ecological Knowledge (FEK) (Hind 2015, Bradford et al 2019). Building the social system into traditional biological research has allowed scientists to access information that would never ordinarily be used. Additionally, incorporating FEK into management decisions may forge a stronger relationship between the management agency and resource users, which often results in improved governance (Arlinghaus et al 2019). However, not all FEK data is reliable, with this study showing/highlighting differences in the responses between specialist and non-specialist spearfishers (Chapter 4). Although these results were preliminary, they suggest that the introduction of the concept of specialisation may be necessary to reduce the subjectivity of FEK.

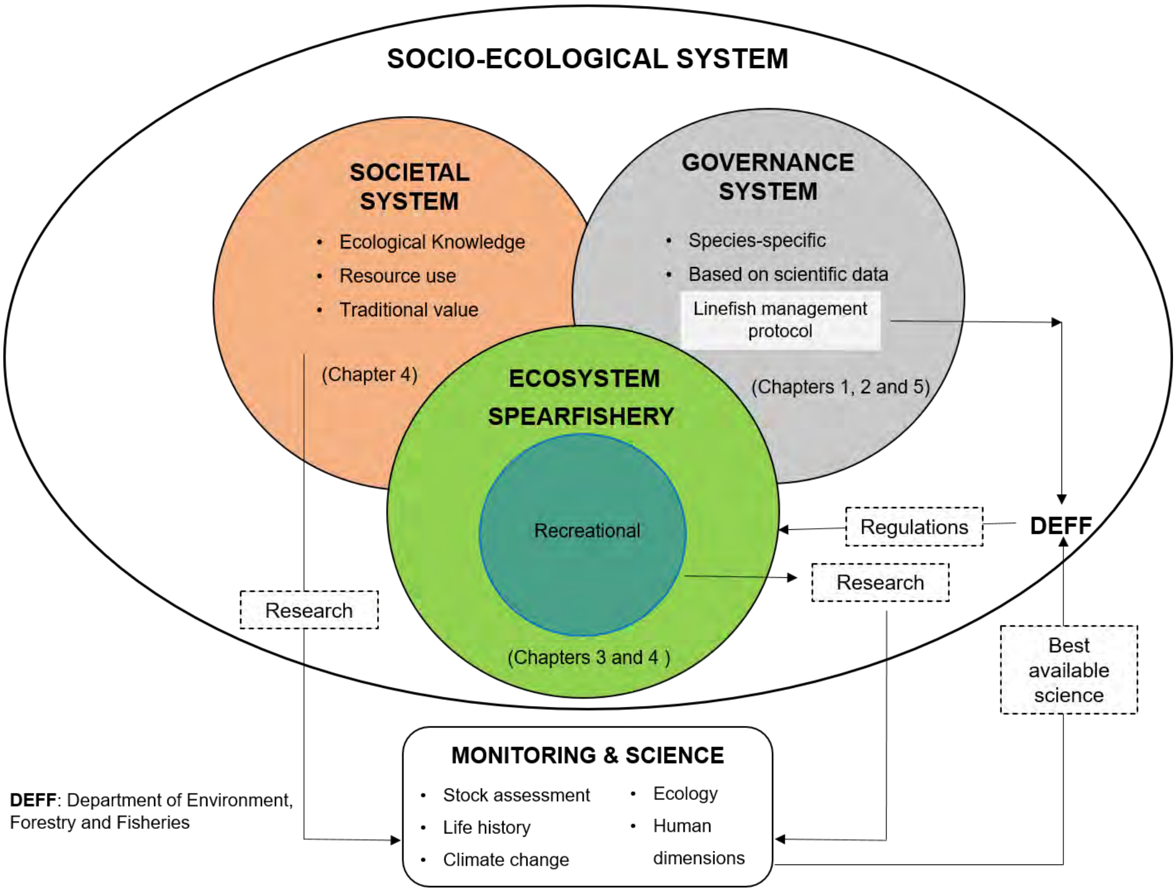

Figure 5.1: The social-ecological system (SES) developed for *Oplegnathus conwayi*, adapted from Ostrom (2009) and Potts et al 2020a. The SES is subdivided into three core systems, including the ecosystem (South Africa's recreational spearfishery species, specifically *Oplegnathus conwayi*), societal system (recreational spearfishers) and the governance system. The Chapters relevant to each system are included in parenthesis.

The specialist spearfishers who participated in the survey further emphasised the importance of *O. conwayi* in Eastern Cape and Western Cape spearfishery, with a core distribution being observed in the Eastern Cape (Chapter 4). Respondents indicated a slight decline in *O. conwayi* since they first started diving (Chapter 4). A new maximum depth of 40 m was noted for this species, although the primary depth range was suggested to be between 10 and 15 m (Chapter 4). An onshore-offshore migration was also noted for this species (Chapter 4). Like that observed in Chapter 3, respondents indicated a protracted spawning period for *O. conwayi* (Chapter 4), with a peak in spawning during spring, which correlated with results from Chapter 3. Seven of the specialised respondents from this Chapter provided valuable information on the spawning behaviour of *O. conwayi*, with respondents indicating that they had observed *O. conwayi* forming spawning aggregations when reproducing. These aggregations were observed in various places on the coastline, indicating coastline-wide spawning. The information collected from Chapter 4 proved that specialist FEK from spearfishers could be a useful source of information for other understudied species that are targeted in this fishery. Despite the alignment of these findings, one must be cognisant of the potential subjectivity and recall-bias of survey respondents in these studies (Nadasdy 2003, Gilchrist et al 2005, Shackeroff and Campbell 2007). To reduce these potential biases, the use of specialists and the combination of traditional and FEK data is recommended, particularly when the information will be used directly to make management recommendations.

There is a wealth of biological information on South Africa's coastal fishery species (Mann 2013). Despite this, many coastal species are overexploited, and this has been mainly attributed to poor governance (Potts et al 2020b) and, in particular, a lack of fisher compliance (Brouwer et al 1997, Kramer et al 2017, Bova et al 2018, Hewett 2019). While there are clear species-specific regulations for most species targeted in the recreational linefishery, this is not the case for species (like *O. conwayi*) that are exclusively targeted in the recreational spearfishery. While studies like this provide ideal information for the development of precautionary regulations, improved monitoring of this fishery is necessary to conduct stock assessments on these species.

The lack of biological and catch data on species targeted by spearfishers is not unique to South Africa. Spearfishery's worldwide are all facing the same issues, with few countries directing research toward these fisheries. While research is being conducted in Australia (Frisch et al 2008, Fairclough et al 2014, Young et al 2015, Bradford et al 2019), Italy (Bulleri and Benedetti-Cecchi 2014), Jamaica (Passley et al 2010) and Spain (Pita and Freire 2014, Pita and Freire 2016, Pita et al 2020, Jiménez-Alvarado et al 2020), this research is insufficient when compared to the amount of data needed in these fisheries, which makes informing optimal governance of these fisheries difficult. However, studies such as this one do provide a straightforward methodology to improve the lack of governance and data on species, particularly in developing countries with low research budgets (Fairclough et al 2014). The use of recreational spearfishers for sample augmentation and FEK is key to collecting data on species that are not easily accessible. Unfortunately, such collaboration with spearfishers is rare. In particular, competitions offer a valuable opportunity for the collection of life history and FEK data for data-limited species. Competitions can also be used to update current life history information of species also targeted by other fisheries. South Africa for example has a large proportion of linefish species with outdated life history data (Mann 2013, Mann 2020).

Collaboration with the competitive spearfishers using the methods outlined in this thesis may provide opportunities for the collection of biological data on data-limited species and species targeted by other coastal fishery sectors.

The *Oplegnathidae* genus is severely understudied, with this study being the first full life history assessment of any of the seven species. The histology and reproductive development data provide a good baseline for future studies within this genus. The vulnerable life-history strategies observed in this study also emphasise the need for research and development of management strategies for this genus worldwide and in South Africa. A good example of one of these species is *Oplegnathus robinsoni*, which are commonly targeted by South African spearfishers, particularly in KwaZulu-Natal. The insights gained in this study suggest that precautionary management measures may be necessary for all of the *Oplegnathidae* species, including *O. robinsoni*.

Some of the future needs for this species include an examination of the effects of climate change on *O. conwayi* through physiological research that focusses specifically on the thermal tolerance of the species (at all life stages).This information, when combined with ocean models, could be used to predict potential shifts in the distribution of the species. There is already some evidence for a potential shift, with one specialist respondent indicating that there has been a major reduction of *O. conwayi* on the KwaZulu-Natal north coast over the years he has been spearfishing. Combined thermal-tolerance and species-distribution modelling studies may not only be relevant to *O. conwayi,* but also all the other target species in the spearfishery, including *O. robinsoni*, *Chirodactylus jessicalenorum* and *C. grandis*.

The combined data from Chapters 3 and 4 provided clear and valuable information for implementing regulations for *O. conwayi*. Based on the size-at–maturity data for the species (Chapter 3), and the support of this by the specialised spearfishers (Chapter 4), a minimum size limit of 400 mm is recommended. The slight decline in the abundance, size and catches of *O. conwayi* indicated by respondents in Chapter 4 supports a proposed reduction in the bag limit, perhaps from five to two per person per day. This reduction is also a precautionary measure until a stock assessment can be conducted. While closed seasons have been widely advocated as a means of protecting species during their vulnerable spawning period (Cochrane 2002), the extended spawning season (Chapters 3 and 4) suggests that this measure may not be effective, based on available evidence. With the advised management measures and protection from South Africa's growing Marine Protected Area network, the harvest of *O. conwayi* in the spearfishery should remain sustainable.

Finally, the combination of traditional fisheries data collection methods, with additional support from spearfishers and the incorporation of spearfishers FEK, was successful, with valuable biological and life history information collected for *O. conwayi*. This not only provided an appropriate approach for future fisheries research in the South African spearfishery, but it has also strengthened the relationship between spearfishers, scientists and managers, which is sorely needed in South Africa's coastal fisheries.

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Appendices

Appendix 1: Details (fish length, weight, age, sex and life stage) of *Oplegnathus conwayi* collected at specific locations in the warm-temperate (WT), sub-tropical (ST) and cool-temperate (CT) coastal regions of South Africa during this study period, between February 2019 and January 2020. CS (Citizen scientists), RS (Routine Sampling), C (Competitions). The gaps in the data are as a result of fish collected from citizen scientists where specimens were not always whole.

Fish ID	Date	Collection Location	Temperate Region	Collection Method	Fork Length (mm)	Total Length (mm)	Weight (G)	Age	Sex	Macroscopic Stage
WT01-01	2019/02/05	Boknes	WT	RS	377	410	1131	-	Male	2 (Resting)
WT01-02	2019/02/05	Boknes	WT	RS	450	492	2177	11	Male	3 (Developing)
WT01-03	2019/02/05	Boknes	WT	RS	455	482	2210	11	Female	3 (Developing)
WT01-04	2019/02/05	Boknes	WT	RS	420	449	1421	10	Female	3 (Developing)
WT01-05	2019/02/05	Boknes	WT	RS	362	391	936	8	Male	2 (Resting)
WT01-06	2019/02/05	Boknes	WT	RS	362	389	1100	-	Female	3 (Developing)
WT01-07	2019/02/05	Boknes	WT	RS	424	455	-	13	Male	3 (Developing)
WT01-08	2019/02/05	Boknes	WT	RS	404	431	1700	1	Male	3 (Developing)
WT01-09	2019/02/05	Boknes	WT	RS	366	397	1300	9	Female	2 (Resting)
WT01-10	2019/02/06	Kenton-on-Sea	WT	RS	489	511	2647	9	Male	2 (Resting)
WT01-11	2019/02/06	Kenton-on-Sea	WT	RS	410	427	1420	11	Male	2 (Resting)
WT01-12	2019/02/06	Kenton-on-Sea	WT	RS	399	417	1321	10	Female	2 (Resting)
WT01-13	2019/02/06	Kenton-on-Sea	WT	RS	415	437	1584	10	Male	2 (Resting)
WT01-14	2019/02/06	Kenton-on-Sea	WT	RS	415	447	1458	-	Male	2 (Resting)
WT01-15	2019/02/06	Kenton-on-Sea	WT	RS	400	430	1442	8	Male	2 (Resting)
WT01-16	2019/02/06	Kenton-on-Sea	WT	RS	401	432	1286	10	Female	2 (Resting)
WT01-17	2019/02/06	Kenton-on-Sea	WT	RS	199	204	157	2	Juvenile	1 (Juvenile)
WT01-18	2019/02/02	Port Alfred	WT	CS	600	645	-	22	-	-

WT01-19	2019/02/05	East London	WT	CS	385	415	-	10	-	-
WT01-20	2019/02/06	East London	WT	CS	433	454	-	14	-	-
WT01-21	2019/02/07	East London	WT	CS	429	459	-	8	-	-
WT01-22	2019/02/08	East London	WT	CS	390	415	-	8	-	-
WT01-23	2019/02/09	East London	WT	CS	380	406	-	11	-	-
WT01-24	2019/02/14	East London	WT	CS	411	439	-	11	-	-
WT01-25	2019/02/15	East London	WT	CS	429	449	-	-	-	-
WT01-26	2019/02/16	East London	WT	CS	420	446	-	8	-	-
WT02-01	2019/03/16	Kenton-on-Sea	WT	RS	353	385	1000	-	Juvenile	1 (Juvenile)
WT02-02	2019/03/16	Kenton-on-Sea	WT	RS	380	399	1290	7	Female	3 (Developing)
WT02-03	2019/03/16	Kenton-on-Sea	WT	RS	445	478	1935	8	Male	2 (Resting)
WT02-04	2019/03/16	Kenton-on-Sea	WT	RS	495	530	2620	12	Female	4 (Ripe)
WT02-05	2019/03/16	Kenton-on-Sea	WT	RS	145	150	75	1	Juvenile	1 (Juvenile)
WT02-06	2019/03/16	Kenton-on-Sea	WT	RS	359	380	1025	7	Juvenile	1 (Juvenile)
WT02-07	2019/03/16	Kenton-on-Sea	WT	RS	331	355	845	-	Female	2 (Resting)
WT02-08	2019/03/16	Kenton-on-Sea	WT	RS	322	341	820	9	Female	2 (Resting)
WT02-09	2019/03/16	Kenton-on-Sea	WT	RS	449	482	1925	13	Male	3 (Developing)
WT02-10	2019/03/16	Kenton-on-Sea	WT	RS	480	511	2195	11	Male	5 (Spent)
WT02-11	2019/03/16	Kenton-on-Sea	WT	RS	387	420	1380	10	Female	2 (Resting)
WT02-12	2019/03/19	Kenton-on-Sea	WT	RS	344	370	860	4	Juvenile	1 (Juvenile)
WT02-13	2019/03/19	Kenton-on-Sea	WT	RS	335	355	770	4	Juvenile	1 (Juvenile)
WT02-14	2019/03/19	Kenton-on-Sea	WT	RS	329	347	760	6	Juvenile	1 (Juvenile)
WT02-15	2019/03/19	Kenton-on-Sea	WT	RS	417	451	1910	11	Female	2 (Resting)
WT02-16	2019/03/19	Kenton-on-Sea	WT	RS	454	490	2285	10	Male	2 (Resting)
WT02-17	2019/03/19	Kenton-on-Sea	WT	RS	427	458	1630	7	Male	5 (Spent)
WT02-18	2019/03/19	Kenton-on-Sea	WT	RS	344	372	860	-	Juvenile	1 (Juvenile)
WT02-19	2019/03/19	Kenton-on-Sea	WT	RS	442	475	1700	8	Female	5 (Spent)
WT02-20	2019/03/19	Kenton-on-Sea	WT	RS	449	481	1990	-	Male	5 (Spent)

WT02-21	2019/03/19	Kenton-on-Sea	WT	RS	472	502	2540	12	Male	2 (Resting)
WT02-22	2019/03/19	Kenton-on-Sea	WT	RS	409	439	1460	-	Female	3 (Developing)
WT03-01	2019/04/26	Kenton-on-Sea	WT	RS	455	489	2025	7	Male	3 (Developing)
WT03-02	2019/04/26	Kenton-on-Sea	WT	RS	385	415	1170	-	Male	2 (Resting)
WT03-03	2019/04/26	Kenton-on-Sea	WT	RS	293	311	495	3	Juvenile	1 (Juvenile)
WT03-04	2019/04/26	Kenton-on-Sea	WT	RS	378	395	1115	8	Male	5 (Spent)
WT03-05	2019/04/27	Kenton-on-Sea	WT	RS	402	430	1595	10	Female	3 (Developing)
WT03-06	2019/04/27	Kenton-on-Sea	WT	RS	340	365	850	-	Female	2 (Resting)
WT03-07	2019/04/27	Kenton-on-Sea	WT	RS	340	365	845	5	Male	2 (Resting)
WT03-08	2019/04/27	Kenton-on-Sea	WT	RS	374	404	1135	-	Male	5 (Spent)
WT03-09	2019/04/27	Kenton-on-Sea	WT	RS	379	394	935	7	Female	2 (Resting)
WT03-10	2019/04/27	Kenton-on-Sea	WT	RS	419	449	1880	8	Male	5 (Spent)
WT03-11	2019/04/27	Kenton-on-Sea	WT	RS	336	361	770	-	Juvenile	1 (Juvenile)
WT03-12	2019/04/27	Kenton-on-Sea	WT	RS	450	481	2065	-	Male	2 (Resting)
WT03-13	2019/04/27	Kenton-on-Sea	WT	RS	475	514	2730	11	Female	5 (Spent)
WT03-14	2019/04/27	Kenton-on-Sea	WT	RS	340	375	795	6	Juvenile	1 (Juvenile)
WT03-15	2019/04/27	Kenton-on-Sea	WT	RS	455	480	1945	14	Male	2 (Resting)
WT03-16	2019/04/27	Kenton-on-Sea	WT	RS	369	385	995	6	Male	5 (Spent)
WT03-17	2019/04/27	Kenton-on-Sea	WT	CS	420	454	-	8	Male	3 (Developing)
WT03-18	2019/04/27	Kenton-on-Sea	WT	CS	400	431	-	-	Male	2 (Resting)
WT03-19	2019/04/27	Kenton-on-Sea	WT	CS	472	510	-	10	Male	2 (Resting)
WT03-20	2019/04/27	Kenton-on-Sea	WT	RS	274	292	455	3	Juvenile	1 (Juvenile)
WT03-21	2019/04/27	Kenton-on-Sea	WT	RS	211	224	220	2	Juvenile	1 (Juvenile)
WT03-22	2019/04/27	Kenton-on-Sea	WT	RS	210	224	205	2	Juvenile	1 (Juvenile)
WT03-23	2019/04/27	Kenton-on-Sea	WT	RS	200	212	90	0	Juvenile	1 (Juvenile)
WT04-01	2019/05/13	Kenton-on-Sea	WT	RS	428	454	1331	7	Female	3 (Developing)
WT04-02	2019/05/13	Kenton-on-Sea	WT	RS	445	471	1842	10	Female	3 (Developing)
WT04-03	2019/05/13	Kenton-on-Sea	WT	CS	361	390	-	-	Male	2 (Resting)

WT04-04	2019/05/13	Kenton-on-Sea	WT	CS	346	371	-	-	Juvenile	1 (Juvenile)
WT04-05	2019/05/13	Kenton-on-Sea	WT	RS	272	291	418	-	Juvenile	1 (Juvenile)
WT04-06	2019/05/19	Boknes	WT	RS	460	486	2199	13	Male	3 (Developing)
WT04-07	2019/05/19	Boknes	WT	RS	440	472	1898	13	Male	5 (Spent)
WT04-08	2019/05/19	Boknes	WT	RS	341	377	819	-	Juvenile	1 (Juvenile)
WT04-09	2019/05/19	Boknes	WT	CS	401	430	-	-	Male	2 (Resting)
WT04-10	2019/05/19	Boknes	WT	CS	445	481	-	12	Female	3 (Developing)
WT04-11	2019/05/19	Boknes	WT	CS	429	460	-	13	Male	5 (Spent)
WT04-12	2019/05/19	Boknes	WT	RS	298	305	448	7	Female	2 (Resting)
WT04-13	2019/05/19	Boknes	WT	RS	300	319	538	3	Female	2 (Resting)
WT04-14	2019/05/20	Kenton-on-Sea	WT	RS	485	520	2579	-	Female	3 (Developing)
WT04-15	2019/05/20	Kenton-on-Sea	WT	RS	355	378	945	-	Male	2 (Resting)
WT04-16	2019/05/20	Kenton-on-Sea	WT	RS	395	415	1125	10	Female	2 (Resting)
WT04-17	2019/05/20	Kenton-on-Sea	WT	RS	298	316	517	-	Juvenile	1 (Juvenile)
WT04-18	2019/05/20	Kenton-on-Sea	WT	RS	310	333	656	4	Juvenile	1 (Juvenile)
WT04-19	2019/05/20	Kenton-on-Sea	WT	RS	415	436	1604	-	Female	2 (Resting)
WT05-01	2019/06/01	Kenton-on-Sea	WT	RS	471	510	2217	13	Male	2 (Resting)
WT05-02	2019/06/01	Kenton-on-Sea	WT	RS	361	386	937	-	Juvenile	1 (Juvenile)
WT05-03	2019/06/01	Kenton-on-Sea	WT	RS	330	354	724	-	Juvenile	1 (Juvenile)
WT05-04	2019/06/01	Kenton-on-Sea	WT	RS	310	330	628	4	Juvenile	1 (Juvenile)
WT05-05	2019/06/01	Kenton-on-Sea	WT	RS	439	468	1804	-	Male	5 (Spent)
WT05-06	2019/06/04	Boknes	WT	RS	487	521	2415	-	Male	3 (Developing)
WT05-07	2019/06/04	Boknes	WT	RS	319	344	722	-	Juvenile	-
WT05-08	2019/06/16	Port Alfred	WT	CS	460	505	-	-	Male	5 (Spent)
WT05-09	2019/06/16	Port Alfred	WT	CS	491	525	-	-	Male	2 (Resting)
WT05-10	2019/06/16	Port Alfred	WT	CS	485	503	-	-	-	-
WT05-11	2019/06/16	Port Alfred	WT	CS	420	451	-	-	-	-
WT05-12	2019/06/17	Kenton-on-Sea	WT	CS	438	496	-	15	-	-

WT05-13	2019/06/17	Kenton-on-Sea	WT	CS	434	460	-	10	-	-
WT05-14	2019/06/17	Kenton-on-Sea	WT	CS	291	311	-	4	-	-
WT06-01	2019/07/24	Boknes	WT	RS	479	501	2574	-	Male	2 (Resting)
WT06-02	2019/07/24	Boknes	WT	RS	526	546	2700	-	Female	5 (Spent)
WT06-03	2019/07/24	Boknes	WT	RS	323	336	610	5	Juvenile	1 (Juvenile)
WT06-04	2019/07/24	Boknes	WT	RS	285	329	444	0	Juvenile	1 (Juvenile)
WT06-05	2019/07/24	Boknes	WT	RS	260	270	361	0	Juvenile	1 (Juvenile)
WT06-06	2019/07/24	Boknes	WT	RS	319	339	682	1	Juvenile	1 (Juvenile)
WT06-07	2019/07/24	Boknes	WT	RS	231	242	252	2	Juvenile	1 (Juvenile)
WT06-08	2019/07/24	Boknes	WT	CS	394	419	-	6	Male	2 (Resting)
WT06-09	2019/07/24	Boknes	WT	CS	438	465	-	8	Male	2 (Resting)
WT06-10	2019/07/24	Boknes	WT	CS	424	452	-	9	Male	2 (Resting)
WT06-11	2019/07/29	Kenton-on-Sea	WT	RS	526	554	3556	-	Male	3 (Developing)
WT06-12	2019/07/29	Kenton-on-Sea	WT	RS	402	426	1279	-	Juvenile	1 (Juvenile)
WT06-13	2019/07/29	Kenton-on-Sea	WT	RS	438	464	1562	10	Male	2 (Resting)
WT06-14	2019/07/29	Kenton-on-Sea	WT	RS	339	358	834	5	Juvenile	1 (Juvenile)
WT06-15	2019/07/29	Kenton-on-Sea	WT	RS	335	351	778	7	Juvenile	1 (Juvenile)
WT06-16	2019/07/29	Kenton-on-Sea	WT	RS	314	336	647	6	Juvenile	1 (Juvenile)
WT06-17	2019/07/29	Kenton-on-Sea	WT	RS	290	309	479	-	Juvenile	1 (Juvenile)
WT06-18	2019/07/29	Kenton-on-Sea	WT	RS	313	334	620	5	Juvenile	1 (Juvenile)
WT06-19	2019/07/29	Kenton-on-Sea	WT	RS	314	330	599	3	Juvenile	1 (Juvenile)
WT06-20	2019/07/29	Kenton-on-Sea	WT	RS	463	494	1864	9	Female	2 (Resting)
WT07-01	2019/08/05	Kenton-on-Sea	WT	RS	436	462	1600	-	Female	3 (Developing)
WT07-02	2019/08/05	Kenton-on-Sea	WT	RS	480	509	2467	7	Female	2 (Resting)
WT07-03	2019/08/05	Kenton-on-Sea	WT	RS	406	444	1366	9	Female	2 (Resting)
WT07-04	2019/08/05	Kenton-on-Sea	WT	RS	426	448	1595	10	Male	2 (Resting)
WT07-05	2019/08/05	Kenton-on-Sea	WT	RS	344	361	815	4	Juvenile	1 (Juvenile)
WT07-06	2019/08/05	Kenton-on-Sea	WT	RS	362	382	952	8	Juvenile	1 (Juvenile)

WT07-07	2019/08/05	Kenton-on-Sea	WT	RS	306	319	536	-	Juvenile	1 (Juvenile)
WT07-08	2019/08/05	Kenton-on-Sea	WT	RS	308	320	549	5	Juvenile	1 (Juvenile)
WT07-09	2019/08/06	Kenton-on-Sea	WT	RS	230	238	236	1	Juvenile	1 (Juvenile)
WT07-10	2019/08/06	Kenton-on-Sea	WT	RS	240	251	265	-	Juvenile	1 (Juvenile)
WT07-11	2019/08/06	Kenton-on-Sea	WT	RS	168	174	92	1	Juvenile	1 (Juvenile)
WT07-12	2019/08/06	Kenton-on-Sea	WT	RS	164	171	87	0	Juvenile	1 (Juvenile)
WT07-13	2019/08/08	Port Alfred	WT	CS	388	409	-	12	Female	3 (Developing)
WT07-14	2019/08/08	Port Alfred	WT	CS	430	457	-	12	Male	2 (Resting)
WT07-15	2019/08/08	Port Alfred	WT	CS	349	359	-	-	Male	2 (Resting)
WT07-16	2019/08/08	Port Alfred	WT	CS	441	464	-	13	Male	2 (Resting)
WT07-17	2019/08/10	Boknes	WT	RS	472	498	1956	10	Male	2 (Resting)
WT07-18	2019/08/10	Boknes	WT	RS	331	347	776	5	Female	2 (Resting)
WT07-19	2019/08/10	Boknes	WT	RS	349	364	746	-	Juvenile	1 (Juvenile)
WT07-20	2019/08/24	Boknes	WT	RS	374	391	995	7	Juvenile	1 (Juvenile)
WT07-21	2019/08/24	Boknes	WT	RS	309	325	623	8	Juvenile	1 (Juvenile)
WT07-22	2019/08/24	Boknes	WT	RS	232	243	276	1	Juvenile	1 (Juvenile)
WT07-23	2019/08/24	Boknes	WT	RS	284	296	527	9	Juvenile	1 (Juvenile)
WT07-24	2019/08/24	Boknes	WT	RS	393	420	1272	10	Female	3 (Developing)
WT07-25	2019/08/24	Boknes	WT	RS	330	349	728	6	Juvenile	1 (Juvenile)
WT07-26	2019/08/24	Boknes	WT	CS	407	431	-	5	Male	2 (Resting)
WT08-01	2019/09/10	Kenton-on-Sea	WT	RS	360	386	942	7	Juvenile	1 (Juvenile)
WT08-02	2019/09/10	Kenton-on-Sea	WT	RS	509	545	2676	11	Male	3 (Developing)
WT08-03	2019/09/10	Kenton-on-Sea	WT	RS	458	494	1958	12	Male	2 (Resting)
WT08-04	2019/09/10	Kenton-on-Sea	WT	RS	277	293	431	-	Juvenile	1 (Juvenile)
WT08-05	2019/09/10	Kenton-on-Sea	WT	RS	393	417	1107	9	Female	3 (Developing)
WT08-06	2019/09/10	Kenton-on-Sea	WT	RS	317	329	670	8	Juvenile	1 (Juvenile)
WT08-07	2019/09/10	Kenton-on-Sea	WT	RS	355	382	1097	9	Female	2 (Resting)
WT08-08	2019/09/10	Kenton-on-Sea	WT	RS	458	491	2225	10	Male	3 (Developing)

WT08-09	2019/09/10	Kenton-on-Sea	WT	RS	345	365	870	8	Female	2 (Resting)
WT08-10	2019/09/10	Kenton-on-Sea	WT	RS	328	349	697	-	Juvenile	1 (Juvenile)
WT08-11	2019/09/10	Kenton-on-Sea	WT	RS	469	505	2107	12	Male	3 (Developing)
WT08-12	2019/09/10	Kenton-on-Sea	WT	RS	480	519	2537	9	Male	3 (Developing)
WT08-13	2019/09/10	Kenton-on-Sea	WT	CS	241	258	-	-	Juvenile	1 (Juvenile)
WT08-14	2019/09/10	Kenton-on-Sea	WT	CS	338	362	-	6	Juvenile	1 (Juvenile)
WT08-15	2019/09/10	Kenton-on-Sea	WT	CS	488	509	-	13	Female	5 (Spent)
WT08-16	2019/09/10	Kenton-on-Sea	WT	CS	435	462	-	-	Female	3 (Developing)
WT08-17	2019/09/10	Kenton-on-Sea	WT	CS	319	348	-	-	Juvenile	1 (Juvenile)
WT08-18	2019/09/10	Kenton-on-Sea	WT	CS	530	569	-	-	Male	3 (Developing)
WT08-19	2019/09/10	Port Alfred	WT	CS	499	528	-	11	Male	2 (Resting)
WT08-20	2019/09/10	Port Alfred	WT	CS	479	509	-	-	Male	4 (Ripe)
WT08-21	2019/09/10	Port Alfred	WT	CS	350	374	-	-	Juvenile	1 (Juvenile)
WT08-22	2019/09/10	Port Alfred	WT	CS	359	387	-	3	Juvenile	1 (Juvenile)
WT08-23	2019/09/12	Kenton-on-Sea	WT	RS	409	439	1610	9	Female	4 (Ripe)
WT08-24	2019/09/12	Kenton-on-Sea	WT	RS	445	476	1670	10	Male	2 (Resting)
WT08-25	2019/09/12	Kenton-on-Sea	WT	RS	331	251	304	0	Juvenile	1 (Juvenile)
WT08-26	2019/09/12	Kenton-on-Sea	WT	RS	239	254	312	2	Juvenile	1 (Juvenile)
WT08-27	2019/09/12	Kenton-on-Sea	WT	RS	337	362	891	-	Juvenile	1 (Juvenile)
WT08-28	2019/09/12	Kenton-on-Sea	WT	RS	319	342	687	-	Juvenile	1 (Juvenile)
WT08-29	2019/09/12	Kenton-on-Sea	WT	RS	368	388	1125	6	Juvenile	1 (Juvenile)
WT08-30	2019/09/09	Boknes	WT	CS	389	420	-	10	Juvenile	1 (Juvenile)
WT08-31	2019/09/09	Boknes	WT	CS	405	443	-	11	Female	3 (Developing)
WT08-32	2019/09/09	Boknes	WT	CS	491	524	-	12	Male	2 (Resting)
WT08-33	2019/09/09	Boknes	WT	CS	479	508	-	14	-	-
WT08-34	2019/09/17	Port Alfred	WT	RS	429	462	1815	6	Male	2 (Resting)
WT08-35	2019/09/17	Port Alfred	WT	RS	449	485	1757	10	Male	3 (Developing)
WT08-36	2019/09/17	Port Alfred	WT	RS	461	492	2286	-	Male	3 (Developing)

WT08-37	2019/09/17	Port Alfred	WT	CS	425	455	-	8	-	-
WT08-38	2019/09/17	Port Alfred	WT	CS	364	389	-	6	Juvenile	1 (Juvenile)
WT08-39	2019/09/17	Port Alfred	WT	CS	467	498	-	18	Female	3 (Developing)
WT08-40	2019/09/17	Port Alfred	WT	CS	104	108	-	0	Juvenile	1 (Juvenile)
WT09-01	4/10/2019	Kenton-on-Sea	WT	RS	223	245	255	0	Juvenile	1 (Juvenile)
WT09-02	4/10/2019	Kenton-on-Sea	WT	RS	525	566	2712	12	Female	4 (Ripe)
WT09-03	21/10/2019	Kenton-on-Sea	WT	RS	185	192	132	1	Juvenile	1 (Juvenile)
WT09-04	21/10/2019	Kenton-on-Sea	WT	RS	402	422	1432	-	Female	3 (Developing)
WT10-01	2020/11/24	Kenton-on-Sea	WT	RS	249	263	319	1	Juvenile	1 (Juvenile)
WT10-02	2020/11/24	Kenton-on-Sea	WT	RS	471	505	1694	14	Female	5 (Spent)
WT10-03	2020/11/30	Kenton-on-Sea	WT	RS	284	304	470	4	Juvenile	1 (Juvenile)
WT10-04	2020/11/30	Kenton-on-Sea	WT	RS	172	181	120	0	Juvenile	1 (Juvenile)
WT10-05	2020/11/30	Kenton-on-Sea	WT	RS	165	174	95	1	Juvenile	1 (Juvenile)
WT10-06	2020/11/30	Cape St Francis	WT	CS	395	421	-	-	Male	3 (Developing)
WT10-07	2020/11/30	Cape St Francis	WT	CS	392	421	-	-	Female	3 (Developing)
WT10-08	2020/11/30	Cape St Francis	WT	CS	460	487	-	9	Male	4 (Ripe)
WT10-09	2020/11/30	Port Alfred	WT	CS	360	389	-	9	-	-
WT10-10	2020/11/30	Port Alfred	WT	CS	374	404	-	7	-	-
WT11-01	2020/12/08	Kenton-on-Sea	WT	CS	384	409	-	-	Male	5 (Spent)
WT11-02	2020/12/08	Kenton-on-Sea	WT	CS	355	376	-	10	Male	3 (Developing)
WT11-03	2020/12/26	Kenton-on-Sea	WT	CS	397	425	-	11	Female	3 (Developing)
WT11-04	2020/12/26	Kenton-on-Sea	WT	CS	395	412	-	-	Male	5 (Spent)
WT11-05	2020/12/26	Kenton-on-Sea	WT	CS	370	402	-	8	Juvenile	1 (Juvenile)
WT11-06	2020/12/26	Kenton-on-Sea	WT	CS	434	469	-	8	Male	5 (Spent)
WT11-07	2020/12/26	Kenton-on-Sea	WT	CS	475	514	-	13	Male	5 (Spent)
WT11-08	2020/12/31	Kenton-on-Sea	WT	CS	360	385	-	5	Juvenile	1 (Juvenile)
WT11-09	2020/12/31	Kenton-on-Sea	WT	CS	454	489	-	12	Female	2 (Resting)
WT11-10	2020/12/31	Kenton-on-Sea	WT	CS	176	187	-	1	Juvenile	1 (Juvenile)

WT11-11	2020/12/26	Kenton-on-Sea	WT	CS	396	426	-	9	Male	5 (Spent)
WT11-12	2020/12/26	Port Alfred	WT	CS	371	399	-	5	Male	2 (Resting)
WT11-13	2020/12/26	Port Alfred	WT	CS	402	431	-	8	Male	2 (Resting)
WT11-14	2020/12/26	Port Alfred	WT	CS	439	428	-	-	Male	2 (Resting)
WT11-15	2020/12/26	Port Alfred	WT	CS	503	539	-	13	Male	3 (Developing)
WT11-16	2020/12/28	Port Alfred	WT	CS	451	487	-	11	-	-
WT11-17	2020/12/28	Port Alfred	WT	CS	359	379	-	10	-	-
WT11-18	2020/12/28	Port Alfred	WT	CS	391	418	-	5	-	-
WT11-19	2020/12/28	Port Alfred	WT	CS	399	432	-	-	Male	2 (Resting)
WT11-20	2020/12/28	Port Alfred	WT	CS	419	438	-	9	Female	2 (Resting)
WT11-21	2020/12/28	Port Alfred	WT	CS	469	504	-	-	Female	2 (Resting)
WT11-22	2020/12/28	Port Alfred	WT	CS	470	496	-	11	Female	2 (Resting)
WT12-01	2020/01/04	Cape St Francis	WT	RS	430	465	1911	13	Male	1 (Juvenile)
WT12-02	2020/01/04	Cape St Francis	WT	RS	443	475	1834	12	Male	5 (Spent)
WT12-03	2020/01/04	Cape St Francis	WT	RS	358	373	886	-	Juvenile	1 (Juvenile)
WT12-04	2020/01/04	Cape St Francis	WT	RS	321	335	684	4	Juvenile	1 (Juvenile)
WT12-05	2020/01/04	Cape St Francis	WT	RS	317	340	722	6	Juvenile	1 (Juvenile)
WT12-06	2020/01/04	Cape St Francis	WT	RS	344	365	854	-	Female	2 (Resting)
WT12-07	2020/01/04	Cape St Francis	WT	RS	330	350	914	6	Juvenile	1 (Juvenile)
WT12-08	2020/01/04	Cape St Francis	WT	RS	325	346	833	5	Juvenile	1 (Juvenile)
WT12-09	2020/01/04	Cape St Francis	WT	RS	251	279	397	-	Juvenile	1 (Juvenile)
WT12-10	2020/01/15	Kenton-on-Sea	WT	RS	404	436	1439	-	Female	5 (Spent)
WT12-11	2020/01/15	Kenton-on-Sea	WT	RS	472	505	2246	10	Male	5 (Spent)
WT12-12	2020/01/15	Kenton-on-Sea	WT	RS	300	324	636	-	Juvenile	1 (Juvenile)
WT12-13	2020/01/15	Kenton-on-Sea	WT	RS	179	191	139	1	Juvenile	1 (Juvenile)
WT12-14	2020/01/15	Kenton-on-Sea	WT	RS	399	421	1417	6	Male	5 (Spent)
WT12-15	2020/01/15	Kenton-on-Sea	WT	RS	369	392	1025	-	Male	2 (Resting)
WT12-16	2020/01/15	Kenton-on-Sea	WT	RS	364	390	970	7	Male	2 (Resting)

WT12-17	2020/01/15	Kenton-on-Sea	WT	RS	427	458	1875	8	Male	2 (Resting)
WT12-18	2020/01/15	Kenton-on-Sea	WT	CS	455	479	-	9	Female	4 (Ripe)
WT12-19	2020/01/15	Kenton-on-Sea	WT	CS	271	290	-	11	Juvenile	1 (Juvenile)
WT12-20	2020/01/15	Kenton-on-Sea	WT	CS	298	321	-	-	Juvenile	1 (Juvenile)
WT12-21	2020/01/15	Kenton-on-Sea	WT	CS	278	292	-	2	Juvenile	1 (Juvenile)
WT12-22	2020/01/15	Kenton-on-Sea	WT	CS	468	504	-	-	Male	2 (Resting)
WT12-23	2020/01/26	Kenton-on-Sea	WT	RS	479	516	1963	15	Male	5 (Spent)
WT12-24	2020/01/26	Kenton-on-Sea	WT	RS	425	454	1829	10	Male	2 (Resting)
ST02-01	2019/03/22	Hole in the wall	ST	C	440	462	-	7	-	-
ST05-01	2019/06/15	Hole in the Wall	ST	C	485	519	2390	11	Male	2 (Resting)
ST05-02	2019/06/15	Hole in the Wall	ST	C	510	530	2330	11	Male	2 (Resting)
ST05-03	2019/06/15	Hole in the Wall	ST	C	510	540	2210	15	Male	2 (Resting)
ST05-04	2019/06/15	Hole in the Wall	ST	C	525	565	3010	13	Male	3 (Developing)
ST05-05	2019/06/15	Hole in the Wall	ST	C	510	540	2470	13	Female	3 (Developing)
ST05-06	2019/06/15	Hole in the Wall	ST	C	580	620	3170	15	Male	2 (Resting)
ST05-07	2019/06/15	Hole in the Wall	ST	C	520	555	2320	20	Male	5 (Spent)
ST05-08	2019/06/15	Hole in the Wall	ST	C	587	610	3190	18	Male	3 (Developing)
ST05-09	2019/06/15	Hole in the Wall	ST	C	575	608	2950	17	Male	2 (Resting)
ST05-10	2019/06/15	Hole in the Wall	ST	C	550	580	2540	24	Male	2 (Resting)
ST05-11	2019/06/15	Hole in the Wall	ST	C	530	570	-	17	Male	3 (Developing)
ST05-12	2019/06/15	Hole in the Wall	ST	C	500	530	2320	10	Male	2 (Resting)
ST05-13	2019/06/15	Hole in the Wall	ST	C	440	469	1690	11	Male	2 (Resting)
ST05-14	2019/06/15	Hole in the Wall	ST	C	447	460	1470	10	Female	2 (Resting)
ST05-15	2019/06/15	Hole in the Wall	ST	C	505	535	2270	-	Male	5 (Spent)
ST05-16	2019/06/15	Hole in the Wall	ST	C	538	555	2720	-	Male	5 (Spent)
ST05-17	2019/06/15	Hole in the Wall	ST	C	535	575	2820	15	Male	2 (Resting)
ST05-18	2019/06/15	Hole in the Wall	ST	C	480	505	2120	14	Female	3 (Developing)
ST05-19	2019/06/15	Hole in the Wall	ST	C	440	470	1446	17	Female	2 (Resting)

ST05-20	2019/06/15	Hole in the Wall	ST	C	480	505	2090	7	Male	5 (Spent)
ST05-21	2019/06/15	Hole in the Wall	ST	C	520	568	2460	16	Male	5 (Spent)
ST-06-01	2019/07/15	Warner Beach	ST	C	600	655	-	19	-	-
ST-06-02	2019/07/17	Umdloti	ST	C	520	545	-	12	-	-
ST-06-03	2019/07/17	Umdloti	ST	C	500	525	-	-	-	-
ST-06-04	2019/07/19	Bluff	ST	C	580	615	-	16	-	-
ST-06-05	2019/07/19	Bluff	ST	C	600	635	-	26	-	-
ST-06-06	2019/07/19	Bluff	ST	C	570	615	-	27	-	-
CT13-01	14-02-2020	Struisbaai	CT	C	339	364	870	9	-	-
CT13-02	14-02-2020	Struisbaai	CT	C	296	312	608	7	-	-
CT13-03	14-02-2020	Struisbaai	CT	C	370	394	1029	-	-	-
CT13-04	14-02-2020	Struisbaai	CT	C	315	335	683	9	-	-
CT13-05	14-02-2020	Struisbaai	CT	C	345	371	801	-	-	-
CT13-06	14-02-2020	Struisbaai	CT	C	329	352	759	-	-	-
CT13-07	14-02-2020	Struisbaai	CT	C	302	322	638	6	-	-
CT13-08	14-02-2020	Struisbaai	CT	C	430	460	1730	10	-	-
CT13-09	14-02-2020	Struisbaai	CT	C	364	386	970	9	-	-
CT13-10	14-02-2020	Struisbaai	CT	C	411	436	1513	13	-	-
CT13-11	14-02-2020	Struisbaai	CT	C	327	349	690	7	-	-
CT13-12	14-02-2020	Struisbaai	CT	C	413	441	1391	9	-	-
CT13-13	14-02-2020	Struisbaai	CT	C	389	421	1332	9	-	-
CT13-14	14-02-2020	Struisbaai	CT	C	459	492	2011	12	-	-
CT13-15	14-02-2020	Struisbaai	CT	C	404	436	1528	11	-	-
CT13-16	14-02-2020	Struisbaai	CT	C	433	470	1855	12	-	-
CT13-17	14-02-2020	Struisbaai	CT	C	423	448	1713	12	-	-
CT13-18	14-02-2020	Struisbaai	CT	C	390	418	1216	-	-	-
CT13-19	14-02-2020	Struisbaai	CT	C	379	402	1168	10	-	-
CT13-20	14-02-2020	Struisbaai	CT	C	396	422	1299	12	-	-

CT13-21	14-02-2020	Struisbaai	CT	C	377	399	1188	9	-	-
CT13-22	14-02-2020	Struisbaai	CT	C	439	467	-	10	-	-
CT13-23	14-02-2020	Struisbaai	CT	C	459	482	-	-	-	-
CT13-24	14-02-2020	Struisbaai	CT	C	391	420	-	11	-	-
CT13-25	14-02-2020	Struisbaai	CT	C	413	431	-	11	-	-
CT13-26	14-02-2020	Struisbaai	CT	C	409	435	-	11	-	-
CT13-27	14-02-2020	Struisbaai	CT	C	409	434	-	7	-	-

Appendix 2: A copy of the online survey disseminated for this study.

Cape knifejaw

Dear Spearfisher

Many species targeted by spearfishers are severely under researched. My master's thesis, through the Department of Ichthyology and Fisheries Science, at Rhodes University, aims to investigate the biology of Cape knifejaw, one of the most commonly harvested species by spearfishers. I will be specifically looking at the age-and-growth, reproduction, reproductive style and any other relevant information. Below is a brief questionnaire on the South African spearfishery specifically focusing on the Cape knifejaw (Oplegnathus conwayi). This questionnaire was created to incorporate your knowledge into our assessment on the biology of Cape knifejaw, as we recognise you as a valuable source of information.

The survey is completely voluntary and can be done anonymously. All the information collected will be aggregated and used for scholarly purposes only. Information collected here is kept confidential and the research is not affiliated with any law enforcement agencies.

For further information or questions, please contact:
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Rhodes University ethics number: 2019-0641-2031

PLEASE NOTE: Participants who complete the questionnaire must be over 18
*Required

1. Do you understand that your participation is entirely voluntary and do you agree to take part in this study: *

   Mark only one oval.

   - Yes
   - No

2. Do you agree to the information collected in this survey being used for research and future comparative studies: *

   Mark only one oval.

   - Yes
   - No

Section A (Target Species)

3. What group of fish do you target more frequently? *

Mark only one oval.

- Game fish
- Bottomfish
- Both

4. Please state the three species you most frequently shoot? (E.g. Species 1: Couta, Species 2: Dusky kob, Species 3: White musselcracker) *

_____

5. Species 1 (as you indicated above): i) In the time you have been spearfishing have you noticed a change in the abundance of species 1 in your region? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease						Large Increase

6. Species 1(as you indicated above): ii) In the time you have been spearfishing have you noticed a change in the size of species 1? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease						Large Increase

7. Species 1(as you indicated above): iii) In the time you have been spearfishing have you noticed a change in the catches of species 1? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

8. Species 2 (as you indicated above): i) In the time you have been spearfishing have you noticed a change in the abundance of species 2 in your region? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

9. Species 2 (as you indicated above): ii) In the time you have been spearfishing have you noticed a change in the size of species 2? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

10. Species 2 (as you indicated above): iii) In the time you have been spearfishing have you noticed a change in the catches of species 2? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

11. Species 3 (as you indicated above): i) In the time you have been spearfishing have you noticed a change in the abundance of species 3 in your region? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	◯	◯	◯	◯	◯	Large Increase

12. Species 3 (as you indicated above): ii) In the time you have been spearfishing have you noticed a change in the size of species 3? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	◯	◯	◯	◯	◯	Large Increase

13. Species 3 (as you indicated above): iii) In the time you have been spearfishing have you noticed a change in the catches of species 3? *

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	◯	◯	◯	◯	◯	Large Increase

14. How often do you see Cape knifejaw? *

Mark only one oval.

- Very Often
- Often
- Occasionally
- Seldom
- Never

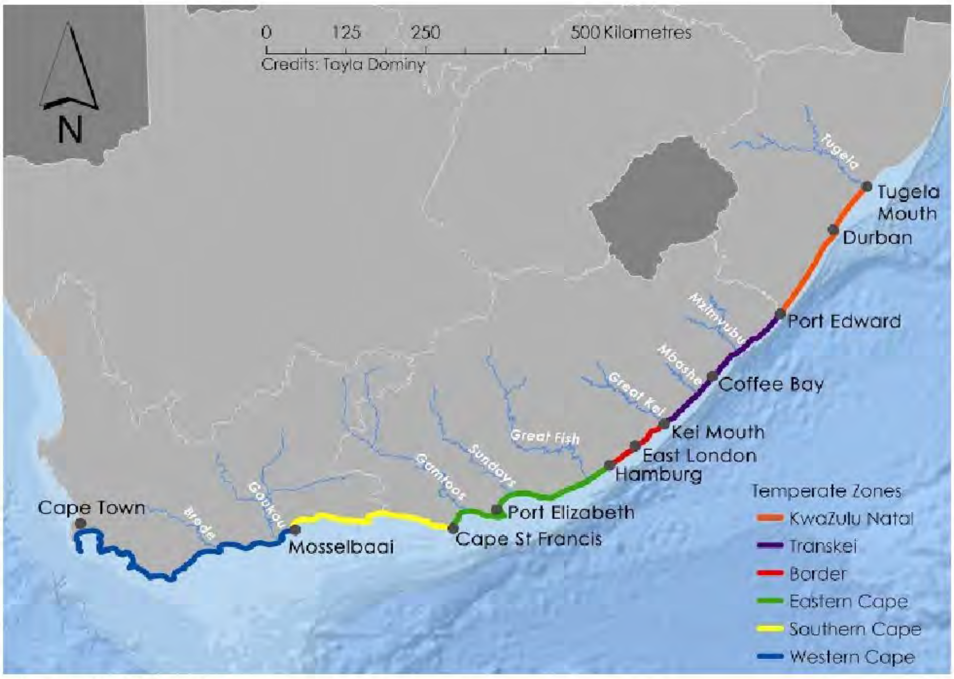
15. How often do you shoot Cape knifejaw? *

Mark only one oval.

- Very Often
- Often
- Occasionally
- Seldom
- Never

16. What percentage of your catch by number do Cape knifejaw comprise? (give answer as a percentage of your total spearfishing catch) *

17. In your opinion where are Cape knifejaw most common? *



Mark only one oval.

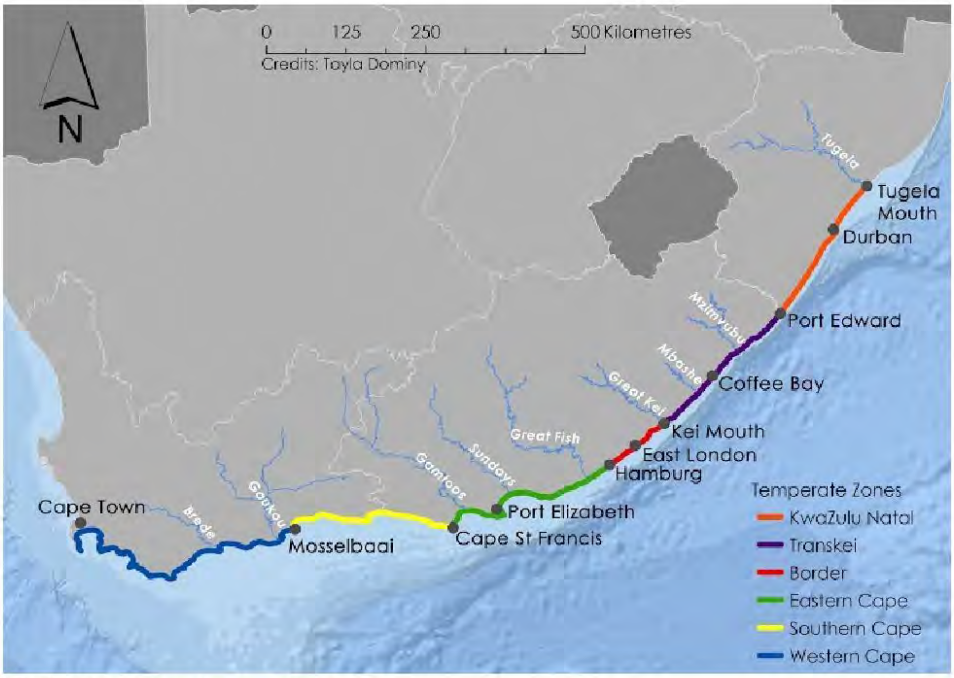
- Evenly distributed
- KwaZulu Natal
- Transkei
- Border
- Eastern Cape
- Southern Cape
- Western Cape

18. Are Cape knifejaw an abundant species in your primary spearfishing region? *

Mark only one oval.

	1	2	3	4	5	
Low Abundance	◯	◯	◯	◯	◯	Highly Abundant

19. In your opinion where are the largest Cape knifejaw most common? *



Mark only one oval.

- Evenly distributed
- KwaZulu Natal
- Transkei
- Border
- Eastern Cape
- Southern Cape
- Western Cape

20. At what depth range do you commonly find the largest Cape knifejaw? *

Tick all that apply.

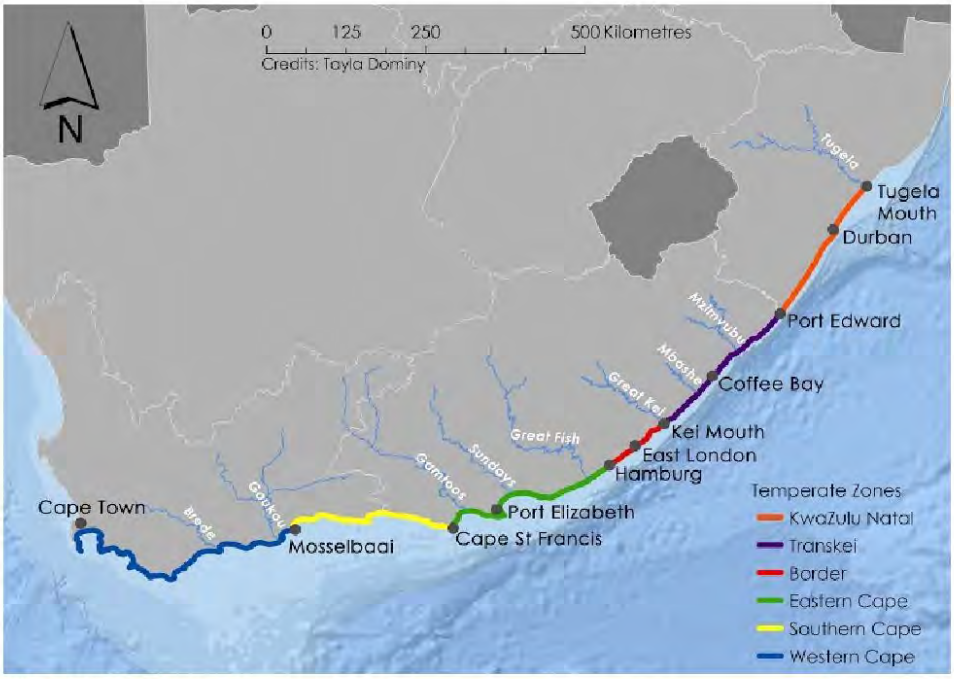
- [ ] 0-5m
- [ ] 6-10m
- [ ] 11-15m
- [ ] 16-20m
- [ ] 21-25m
- [ ] 26-30m
- [ ] 31-35m
- [ ] 36-40m
- [ ] 41-45m

21. At what depth range do you commonly find juvenile Cape knifejaw? *

Tick all that apply.

- [ ] 0-5m
- [ ] 6-10m
- [ ] 11-15m
- [ ] 16-20m
- [ ] 21-25m
- [ ] 26-30m
- [ ] 31-35m
- [ ] 36-40m
- [ ] 41-45m

22. In your opinion where are juvenile Cape knifejaw most common? *



Mark only one oval.

- Evenly distributed
- KwaZulu Natal
- Transkei
- Border
- Eastern Cape
- Southern Cape
- Western Cape

23. At what time of the year do you observe the smallest Cape knifejaw individuals? *

Tick all that apply.

- [ ] January
- [ ] February
- [ ] March
- [ ] April
- [ ] May
- [ ] June
- [ ] July
- [ ] August
- [ ] September
- [ ] October
- [ ] November
- [ ] December
- [ ] Unknown

24. In your opinion, when are the breeding months of Cape knifejaw? *

Tick all that apply.

- [ ] January
- [ ] February
- [ ] March
- [ ] April
- [ ] May
- [ ] June
- [ ] July
- [ ] August
- [ ] September
- [ ] October
- [ ] November
- [ ] December
- [ ] Unknown

25. What have you based your previous answer on?

Mark only one oval.

- What others say
- Observing fish gonads
- Observing spawning aggregations
- All of the above
- Other: ______________________

26. In your opinion at what length or weight do Cape knifejaw mature? (Kg's or cm) *

____

27. Have you ever observed a spawning event or a spawning aggregation of Cape knifejaw? *

Mark only one oval.

- Yes
- No

28. If so please could you give a short description? (number of fish; where in the water column; when in the year; where in the country; if fish pair; etc)

____

29. What months are Cape knifejaw most commonly shot in your primary spearfishing region? *

Tick all that apply.

- [ ] January
- [ ] February
- [ ] March
- [ ] April
- [ ] May
- [ ] June
- [ ] July
- [ ] August
- [ ] September
- [ ] October
- [ ] November
- [ ] December
- [ ] All Year

30. Do you think that Cape knifejaw are resident to an area throughout the year or do they undertake migrations? *

Mark only one oval.

- ( ) Resident (remain on the same reef)
- ( ) Migratory (move along the coast)
- ( ) Some are resident while others migrate

31. From your experience have you found Cape knifejaw to be at greater depths during certain times of the year? *

Mark only one oval.

- ( ) Yes
- ( ) No

32. If your previous answer is yes, please state when they are found at greater depths?

Tick all that apply.

- [ ] January
- [ ] February
- [ ] March
- [ ] April
- [ ] May
- [ ] June
- [ ] July
- [ ] August
- [ ] September
- [ ] October
- [ ] November
- [ ] December

Please answer questions 17-19 if Cape knifejaw is not one of your 3 targeted species above.

33. In the time you have been spearfishing have you noticed a change in the abundance of Cape knifejaw in your region?

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	◯	◯	◯	◯	◯	Large Increase

34. In the time you have been spearfishing have you noticed a change in the size of Cape knifejaw?

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

35. In the time you have been spearfishing have you noticed a change in Cape knifejaw catches?

1 = Large Decrease - 3 = No Change - 5 = Large Increase

Mark only one oval.

	1	2	3	4	5	
Large Decrease	⬭	⬭	⬭	⬭	⬭	Large Increase

Section B (Personal Information)

36. Your age range: *

Mark only one oval.

- ⬭ 18 to 23
- ⬭ 23 to 30
- ⬭ 30 to 40
- ⬭ 40 to 50
- ⬭ 50 to 60
- ⬭ 60+

37. Gender: *

Mark only one oval.

- Female
- Male
- Other: ____________________

38. Race: *

Mark only one oval.

- Indian
- Black
- Coloured
- White
- Other: ____________________

39. Highest level of qualification *

Mark only one oval.

- None
- Primary
- Secondary
- Tertiary

40. Employment status *

Mark only one oval.

- Employed
- Student
- Unemployed and looking for work
- Unemployed and not looking for work
- Retired

41. For how many years have you been spearfishing? *

____

42. Approximately how many spearfishing outings do you undertake monthly? *

Mark only one oval.

- 0-2
- 3-5
- 5-10
- More than 10

43. Approximately how many hours do you spend spearfishing per outing? *

Mark only one oval.

- Half Day (less then 4 hours)
- All Day
- 2 or more days

44. When conditions are suitable for spearfishing, how often do you choose to go spearfishing rather than pursue another recreational activity? *

Mark only one oval.

	1	2	3	4	5	
Never Spearfishing	◯	◯	◯	◯	◯	Always Spearfishing

45. How important is the influence of spearfishing on your lifestyle (eg. your social life, reading habits, internet browsing, or work schedule)? *

Mark only one oval.

	1	2	3	4	5	
Not Important	◯	◯	◯	◯	◯	Extremely Important

46. When you spearfish, do you prefer to shoot few large fish or many smaller fish? *

Mark only one oval.

	1	2	3	4	5	
Many small fish	◯	◯	◯	◯	◯	A few large fish

47. How would you judge your overall spearfishing skills compared to the average spearfisher? *

Mark only one oval.

	1	2	3	4	5	
My skills are much lower	◯	◯	◯	◯	◯	My skills are my higher

48. What is your maximum depth (meters) of spearfishing? (Please be realistic) *

Mark only one oval.

- 5m
- 10m
- 15m
- 20m
- 25m
- 30m
- 35m

49. Are you a member of SAUFF? *

Mark only one oval.

- Yes
- No

50. Are you a member of a spearfishing club? If yes, please state the name of the club you belong to. *

____

51. Where do you live (Town/city and province)? *

____

52. What is the closest town to your main spearfishing area? *

____

53. What is your primary means of spearfishing, shore diving or boat diving? *

Mark only one oval.

- Boat diving
- Shore diving
- Both

Competition Details

Please state your name and contact details if you would like to enter the competition to win a R500 spearfishing voucher. If you would like to remain anonymous, please simply leave out your name and contact details.

54. Name:

____

55. Cell Phone number:

____

End Thank you!