Movement, growth and stock assessment of the coastal fish *Lichia amia* (Teleostei: Carangidae) off the South African coast.

by

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Submitted in fulfilment of the academic requirements for the degree of Master of Science in the School of Life & Environmental Sciences, University of KwaZulu-Natal, Durban

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ABSTRACT

The limited range of garrick/leervis *Lichia amia*, its popularity as a gamefish to all sectors of the marine recreational linefishery and the degradation of many estuaries which function as nurseries for this species, has aroused concern about the stock status of this species. In addition, other than a preliminary investigation conducted by ORI in 1992, relatively little research has been undertaken on this important recreational species. Considering the recreational value of *L. amia* and the need to provide a scientific basis for its management, a comprehensive stock assessment was required. This study therefore investigated the biology and stock status of *L. amia* off the South African coast. Through *ad hoc* biological sampling undertaken from 1978-2007 and validation of growth by means of OTC marking, the growth of the *L. amia* population was best described as: $L_t = 1206\, mmFL\left(1 - e^{-0.20[t+1.10 years]}\right)$. Growth was also determined using tag-recapture and length frequency data. The tag-recapture data was further utilized in illustrating the movement behaviour of *L. amia*. Trends in catches were determined from the analysis of catch and effort data from the National Marine Linefish System (NMLS) and Boat Launch Site Monitoring System (BLSMS) databases. This showed a decreasing trend in the *CPUE* of *L. amia* along the KZN coast over time for all sectors of the KZN marine recreational linefishery investigated. The growth parameter estimates from the length-at-age data were used in undertaking a per-recruit assessment of *L. amia*. The results of the spawner-biomass-per-recruit (*SBPR*) model indicate that *L. amia* is at 14% of its unfished level. According to the South Africa's Linefish Management Protocol (LMP), the *L. amia* stock has thus collapsed and appropriate management options to rebuild the stock are discussed.

PREFACE

The work described in this dissertation was carried out at the Oceanographic Research Institute of the School of Life and Environmental Sciences, University of KwaZulu-Natal, Durban from March 2007 to December 2008, under the supervision of Professor Rudy P. van der Elst and Mr Bruce Q. Mann.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others, it is duly acknowledged.

DECLARATION 1 – PLAGIARISM

I, ... declare that

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other university.

3. This dissertation does not contain other persons' data, graphs or other information, unless specifically acknowledged as being sourced from other persons.

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   a. Their words have been re-written but the general information attributed to them has been referenced,
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DECLARATION 2 – PUBLICATIONS

Research presented in this dissertation has not yet contributed to any publications (in preparation, submitted, in press or published) other than an oral presentation at the South African Marine Science Symposium (SAMSS), University of Cape Town (UCT), Cape Town 29 June-3 July 2008:

SMITH, D., MANN, B.Q., FENNESSY, S.T. and VAN DER ELST, R.P. 2008. Biology and stock assessment of the coastal fish *Lichia amia* (Teleostei: Carangidae) off the South African coast. South African Marine Science Symposium, UCT, Cape Town 29 June-3 July 2008.

Signed....................................

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LIST OF ABBREVIATIONS

Organisations:

EKZNW	Ezemvelo KwaZulu-Natal Wildlife (previously known as the KwaZulu-Natal Wildlife, KwaZulu-Natal Nature Conservation Services and Natal Parks Board)
MCM	Marine and Coastal Management (previously known as Sea Fisheries)
ORI	Oceanographic Research Institute
SAIAB	South African Institute for Aquatic Biodiversity
SAMLMA	South African Marine Linefish Management Association

Monitoring systems:

NMLS	National Marine Linefish System
BLSMS	Boat Launch Site Monitoring System

Regions along the South African coast:

Province	Region	Code	Locality code
KZN	Maputaland	MP	3 565 – 3 727
	Zululand	ZL	3732 – 3 909
	Greater Durban	GD	3 910 – 4 005
	South Coast	SC	4 006 – 4 125
Eastern Cape	Transkei	Trans.	4 126 – 4 400
	Border	Bor.	4 403 – 4 546
	Lower Eastern Cape	LEC	4 550 – 4 974
Western Cape	Southern Cape	SCp	4 976 – 5 268
	Lower Western Cape	LWC[1]	5 272 – 5 653

[1] LWC = rest of Western Cape up until Cape Point (5 653)

Ezemvelo KwaZulu-Natal Zones:

BN	Bhanga Nek	BT	Ballito
SD	Sodwana Bay	DB	Durban Area
CV	Cape Vidal	KB	Kingsburgh
SL	St. Lucia	SB	Scottburgh
MP	Mapelane	UT	Umtentweni
RB	Richards Bay	UV	Uvongo
MT	Mtunzini	TF	Trafalgar
TG	Tugela	BT	Ballito

General:

LMP	Linefish Management Protocol	*CPUE*	Catch per unit effort
FL	Fork length (mm)	APE	Average percent error
TL	Total length (mm)	CV	Coefficient of variance
ML	Maxilla length (mm)	D	Index of precision
SL	Standard length (mm)	MZA	Marginal zone analysis
Wt	Weight (kg or g)	SE	Standard Error
Eq.	Equation	Obs.	Observed
Rel.	Released	Exp.	Expected
Rec.	Recaptured	Dev.	Deviance
Insp.	Inspected	*YPR*	Yield-per-recruit
Hrs.	Hours	*SBPR*	Spawner-biomass-per-recruit
Dist.	Distance	*MSY*	Maximum sustainable yield
Ref.	Reference	BOFFF	Big Old Fat Fecund Female Fish
Freq.	Frequency	TLPMF	Traffic Light Precautionary Management Framework
km	Kilometres	TLS	Traffic Light System

CHAPTER 1
Introduction

1.1 Review of the biology of *Lichia amia* (Linnaeus, 1758)

The Carangidae is a diverse family of teleost fishes comprising 151 species in 30 genera. *Lichia amia* belongs to a monospecific genus in the Carangidae family. In the past, there was some confusion about the correct name of this genus. The originally accepted generic name *Hypacanthus* Rafinesque, 1810, was suppressed, as it appeared to be an incorrect spelling of *Hypanacantus* Rafinesque, 1809. Consequently, Cuvier's *Lichia* (1817) was given nomenclatural precedence (Melville, 1979), while the specific name *amia* was derived from Linnaeus' original description of this species as *Scomber amia* in 1758. In South Africa *L. amia* are commonly known as the leervis or garrick. Elsewhere in the world, common names for *L. amia* are liche, especially in French speaking regions, and akya in the Mediterranean. Other common members of the Carangidae family include species from the genera *Caranx* (kingfish), *Scomberoides* (queenfish), *Seriola* (yellowtail) and *Trachinotus* (pompano).

Identifying features

L. amia have a distinct shape and cannot be easily confused with any other fish species, i.e. a slightly concave belly and a distinctive lateral line that is irregular and sinuous, curving over the top of the pectoral fin and then dipping below it without side branches (Smith-Vaniz and Staiger, 1973; Smith and Heemstra, 1986). Adult *L. amia* are silver-grey dorsally and silvery-white below the lateral line, with dark fins and a large deeply forked tail. In contrast, juveniles less than 100 mm in length are characterised by a conspicuous orange-yellow colour with six to seven vertical black bands (Smith, 1949; Smith and Heemstra, 1986). *L. amia* appear to be scaleless having a leathery skin, from which the Afrikaans name "Leervis" was derived. However, minute narrow, oval-shaped embedded scales are present, which are needle-like on the breast (Smith-Vaniz and Staiger, 1973). The dorsal and anal fins consist of two sections; the dorsal fin has seven short isolated spines, while the anal fin has two separate spines (van der Elst, 1988). These spines on the dorsal and anal fins are arranged before a large soft spine, behind which nineteen or twenty rays extend toward the tail (van der Elst, 1988). The dorsal and anal fin lobes are longer than the pectoral fins. *L. amia* has a large mouth that extends back past the eyes, with a protruding lower jaw, which carries villiform teeth and seven to nine gill rakers on the first gill arch (Smith-Vaniz and Staiger, 1973). Unlike other species in the family Carangidae, it has no development of the lateral line scales into scutes (Smith-Vaniz and Staiger, 1973).

Distribution of *Lichia amia*

L. amia has a limited geographic distribution, being confined to parts of the Mediterranean, eastern Atlantic and south-western Indian Ocean, as seen in Figure 1.1 (van der Elst *et al*., 1993). This species is found in the Mediterranean and Black Sea, down the coast of north-west Africa (in particular Mauritania) and along parts of the west coast of Africa to northern Namibia. It is scarce south of Cunene mouth to Table Bay, but increases in abundance from False Bay (near Cape Point) through to northern KwaZulu-Natal (KZN), as illustrated in Figure 1.1 (Biden, 1948; Day, 1967; Day *et al*., 1981; Schoeman, 1978; Smith and Heemstra, 1986). According to van der Elst *et al*. (1993), most of the *L. amia* stock along the South African coast is found between Cape Point and Cape Vidal.

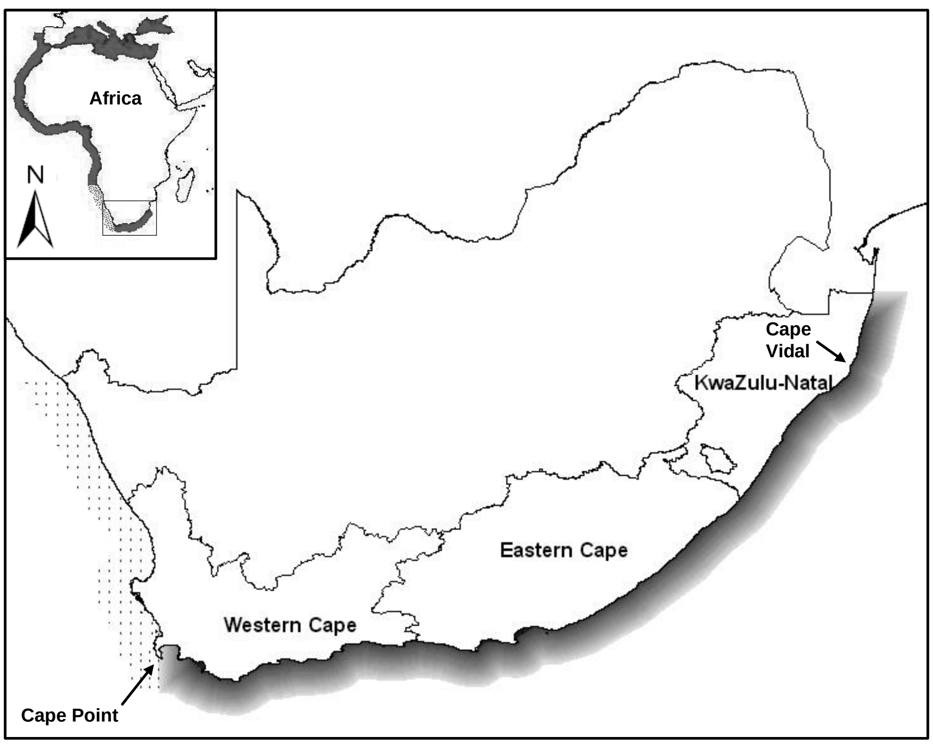


Figure 1.1: Distribution of *Lichia amia* globally and along the South African coast.

With the limited distribution of the *L. amia* stock off the South African coast and the lack of *L. amia* on the west coast of Southern Africa between Cunene mouth and Table Bay, it is possible that separate stocks will be present. Genetic analyses will be needed to determine if these are in fact separate stocks.

Habitat

The mechanism driving the southward dispersal of the early life stages of a number of South Africa's linefish species was originally thought to be the Agulhas Current (van der Elst, 1976; Heydorn *et al*., 1978; Joubert, 1981; van der Elst, 1988; Smale, 1984; Garratt, 1988; van der Elst and Adkin, 1991). However, Beckley (1993) has shown this to be strictly speaking incorrect in a study on the ichthyoplankton found along South Africa's east coast. Beckley (1993) established that oceanographic features and wind forcing associated with the shoreward edge of the Agulhas Current, are the main contributors in the southward dispersal of fish eggs and larvae. Beckley's (1993) study thus indicated that fish larvae are distributed southwards in shelf waters inshore of the Agulhas Current rather than in the Agulhas Current as originally theorised. It is believed that *L. amia* eggs and larvae are distributed southwards by this mechanism.

A recent study by Connell (2007), on the marine fish eggs and larvae from the east coast of South Africa, supports the findings of Beckley (1993). During Connell's (2007) study, *L. amia* eggs were recorded, although rarely, off Park Rynie (60 km south of Durban) from September to November. These eggs were only found in samples taken 5km offshore and not in the Agulhas Current – with its core on average 40-60 km off Durban (Schumann, 1988). The infrequency with which the eggs were recorded, indicated that *L. amia* probably do not spawn in close proximity to Park Rynie. With all the *L. amia* eggs collected in offshore samples, Connell (2007) concluded that they were probably transported by a combination of wind and current from an area further north. Based on the time the eggs take to hatch (~48 hours) the spawning grounds for *L. amia* are thought to be off the Tugela region of the KZN north coast (about 120 km north of Durban) (Connell, 2007). As adult *L. amia* are not known to move far offshore and generally remain within 500 m of the coast (van der Elst *et al*., 1993), it is possible that the eggs are first retained within the Natal gyre before being distributed southwards inshore of the Agulhas Current (A. Connell, *pers. comm.*)

Recruitment of small juveniles between 40-120 mm TL into estuaries of the Cape occurs mainly during late spring and summer, i.e. November to March (Day *et al*., 1981; Ratte, 1982; Beckley, 1983; Beckley, 1984; Hanekom and Baird, 1984; Bennett, 1989a; Whitfield, 1990; Whitfield and Kok, 1992; Quinn *et al*., 1999). These estuaries act as nurseries for juveniles and sub-adults that benefit from reduced predation and higher food availability (Smale and Kok, 1983; Bennett, 1989a; Bennett, 1989b; Whitfield, 1990). Recruitment into estuaries during spring and summer may assist in the survival of the juvenile *L. amia*. According to Cyrus and Blaber (1987) and Bennett (1989a), summer rains increase river flow and aid predator avoidance by increasing turbidity. In addition, Whitfield (1990) noted higher availability of food during summer in comparison to winter, and during summer prolific aquatic vegetation can act as important refuges and habitats (Blaber and Cyrus, 1983; Whitfield, 1984).

Juvenile *L. amia* living in estuaries can tolerate a wide range of salinities (i.e. euryhaline). Blaber and Cyrus (1983) recorded *L. amia* at salinities of between 2 and 38 ‰. According to Day *et al*. (1981), *L. amia* are often found in the upper reaches of estuaries. Additionally, in a study by Blaber and Cyrus (1983), *L. amia* were shown to have an apparent preference for turbid waters with none recorded at turbidities lower than 7.5 NTU but were present at turbidities as high as 76.0 NTU. Many estuaries in South Africa are under threat from increased development in catchment areas, reduced freshwater inflow and increased use of estuarine resources (Lamberth and Turpie, 2003). With a heavy reliance on estuaries as nursery areas in the Cape, this has resulted in the reduction and degradation of habitat availability for juvenile *L. amia* and has thus affected the survival of fish in estuaries (Whitfield, 1997).

Although juvenile *L. amia* have been considered dependent on estuaries as nursery areas (Wallace *et al*., 1984), Lasiak (1981) established that surf-zone waters might also function as important nursery areas for this species off King’s Beach, Port Elizabeth. Similarly, Bennett (1989b) recorded juvenile *L. amia* in a moderately exposed surf-zone in the South-western Cape. Although abundance of juvenile *L. amia* in this surf-zone habitat is low compared to juveniles of other species, Bennett (1989b) concluded that *L. amia* also make use of surf-zones as nurseries.

Wallace and van der Elst (1975) showed that juvenile *L. amia* are rare in KZN estuaries, with cooler, more temperate estuaries and surf-zones in the Eastern and Western Cape acting as the main nursery areas for *L. amia* (Smale and Kok, 1983). Similarly, Blaber and Cyrus (1983) confirmed that although juvenile *L. amia* do occur in all types of KZN estuaries, in comparison to other juveniles and sub-adults of other Carangid species, *L. amia* were fairly rare.

After initial juvenile recruitment and a residence period of approximately 1-3 years, sub-adult *L. amia* (~500 mm FL) leave their nursery areas and join the migrating adult population (Bennett, 1989a; Whitfield, 1990). As an inshore fish species, sub-adult and mature adult *L. amia* are found mainly in the surf-zone, typically within 500 m of the coast (van der Elst *et al*., 1993) and with a preferred depth range of 1-20 m (B. Mann, ORI, *pers. comm.*). Commonly, these *L. amia* will form small shoals along the backline where they are swift and aggressive predators.

Migration

Like a number of other South African linefish species, *L. amia* are seasonally migratory. In winter *L. amia* migrate up to KZN from the Cape, arriving around June, often in association with the annual sardine run (*Sardinops sagax*) and shoals of elf/shad (*Pomatomus saltatrix*). After spawning in spring to early summer, adults migrate back southwards to the cooler Cape waters (Day *et al*., 1981; van der Elst, 1988; Branch *et al*., 2002). According to Smale (1983), this migration is either asynchronous, or part of the population remains behind in the Cape, as adult *L. amia* are caught in Cape waters throughout the year.

The general pattern of movement up the South African coast based on catches (i.e. when *L. amia* are in season) is described by Biden (1948) and Schoeman (1978) as: between False Bay and Hermanus from January to April, Mossel Bay from November to April, between Knysna and Plettenberg Bay from March to May, Port Elizabeth from October to April, East London from March to October, and KZN from late May through to early November.

Feeding

Once recruited into an estuary, juvenile *L. amia* feed aggressively on a variety of prey species (Day *et al*., 1981), and are even able to consume prey fish longer than their own stomach length (Marais, 1984). In order to feed efficiently and avoid larger predators in estuaries, juveniles will seek cover under structure such as vegetation or floating debris, and from this concealed position lunge out and feed on passing fish (Day *et al*., 1981; Smale and Kok, 1983). This was illustrated by Smale and Kok (1983) who recorded juveniles close to aquatic macrophyte beds in the shallows of the Knysna and Swartvlei estuaries. As juvenile *L. amia* start losing their conspicuous yellow and black colouration at a length greater than 100 mm, their feeding behaviour changes. Juveniles >100 mm become a silvery colour and they are often found in close association with schools of mullet of similar size, allowing for an undetected approach towards smaller prey fish which they strike at as soon as they are within range (Smale and Kok, 1983).

Coetzee (1982) stated that *L. amia* is the most important predatory fish in the Swartvlei estuarine system. The importance of *L. amia* within the Knysna estuary was also shown by Day (1967) when studying the trophic relations within the system. In his study, Day (1967) showed that *L. amia* was the top-predator in the food web within the system, as illustrated in Figure 1.2.

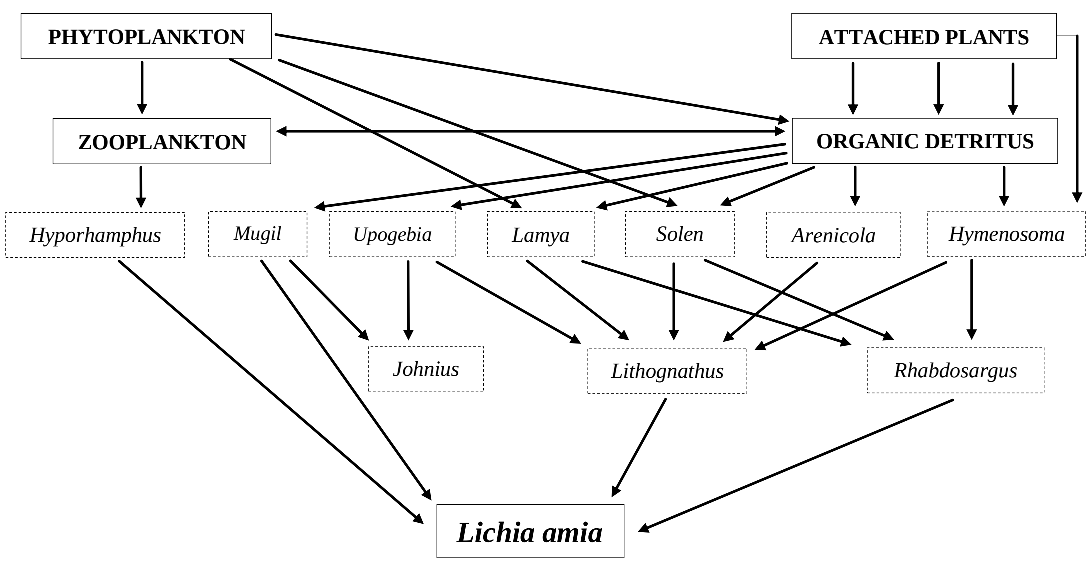


Figure 1.2: Trophic relations between the main biotic and abiotic elements within the Knysna Estuary (Adapted from Day, 1967, p 406).

Previous work on the diet of *L. amia* included analyses undertaken in various Cape (Coetzee, 1982; Smale and Kok, 1983; Marais, 1984; Bennett, 1989c) and KZN estuaries (Whitfield and Blaber, 1978; Blaber and Cyrus, 1983). From these studies, it was shown that the diet of *L. amia* varied greatly with a wide number of different prey species selected due to a number of factors. (See

Appendix I for a detailed summary of the selected prey species in the diet of *L. amia* as found in the above-mentioned studies).

In the studies conducted in various Cape estuaries, the stomach content analyses of *L. amia* revealed changes in prey species selected both spatially within an estuary and according to the size of the predator. Spatial variability in the diet of *L. amia*, within different estuarine systems, was attributed to the relative abundance and accessibility of prey species with *L. amia* generally feeding on whatever prey was available (Ratte and Hanekom, 1980; Coetzee, 1982; Smale and Kok, 1983; Marais, 1984). Although this was the case, differences in the diets of juvenile, sub-adult and adult *L. amia* were found with juveniles showing a greater dependence on estuarine associated crustaceans (e.g. *Palaemon pacificus* and *Penaeus* spp.) and molluscs than sub-adult and adult *L. amia* (Coetzee, 1982; Smale and Kok, 1983; Marais, 1984; Bennett, 1989c). All sub-adult and adult *L. amia* were more or less exclusively piscivorous feeding on a number of different fish species, with Gobiidae and Mugilidae species being common as well as *Hepsetia breviceps* and *Gilchristella aestuarius*.

Within KZN estuaries (Mdloti, Mlalazi, Mtamvuna, and St Lucia estuaries), Blaber and Cyrus (1983) found *L. amia* to be exclusively piscivorous with the exception of a very low frequency of penaeid prawns within their diet. Similarly, Whitfield and Blaber (1978) found *L. amia* to be exclusively piscivorous (mainly Mugilidae and *Rhabdosargus sarba*) within the St Lucia system. However, Blaber and Cyrus (1983) found *L. amia* to prefer comparatively slower moving species (*Oreochromis mossambicus* and *Thryssa vitrirostris*). As with the studies done on the diet of *L. amia* in Cape estuaries, Whitfield and Blaber (1978) attributed prey selection to both prey abundance and accessibility.

Once *L. amia* leave their nursery areas and move to the sea, feeding activities and diet change. Adult *L. amia* hunt in shoals in open water and are known to herd fish in the surf-zone, they may even trap baitfish in a gully before feeding on them (van der Elst, 1988). As in estuaries, fish dominate the diet of *L. amia* in inshore waters with prey species selected being mainly pelagic or shoaling demersal species (Lasiak, 1982; Smale, 1983; van der Elst, 1988; Heemstra and Heemstra, 2004). According to van der Elst (1988) and Heemstra and Heemstra (2004) *P. saltatrix*, *Sarpa salpa* and *Pomadasys olivaceum* are preferred prey species. Lasiak (1982) recorded *L. amia* to have fed on *P. saltatrix*, *Trachurus capensis* and *S. sagax*. In addition, according to Smale (1983), *L.*

amia prey selection differed according to their size. Smaller *L. amia* (401-700 mm FL) were found to have fed mainly on small shoaling pelagic teleosts such as *Trachurus trachurus*, *Engraulis capensis* and *Scomber japonicus*. Larger *L. amia* (701-1200 mm FL), fed predominantly on larger shoaling pelagic prey (i.e. adult *S. sagax* and *S. japonicus*).

Reproduction and maturity

A number of authors have suggested a different length at maturity for *L. amia*. Day *et al*. (1981) and Smith and Heemstra (1986) estimated the length at maturity of *L. amia* to be 550 mm FL. In contrast, van der Elst (1988) stated that maturity is reached at 600 mm FL. In addition, from work done on a fish community in an Eastern Cape surf-zone, Lasiak (1982) noted the presence of ripe male *L. amia* from between 750 and 843 mm TL and proposed that spawning occurred during October. Van der Elst *et al*. (1993) subsequently determined that 50% maturity is attained at 750 mm FL in males and at 850 mm FL in females (~4 years). In this study, van der Elst *et al*. (1993) showed that *L. amia* has a single spawning season that occurs from September through to November during which ripe fish are caught at an approximate sex ratio of 1:1. In a recent study Potts *et al*. (2008) showed that *L. amia*, off the southern Angolan coast, reached 50% maturity at a size of 623 mm FL (2.43 years), had an extended spawning season (June to November) and observed possible spawning aggregations during September and for a shorter period in August. During this time, *L. amia* were caught at a sex ratio of 1 male to 1.9 females that were on average larger than male fish (Potts *et al*., 2008).

Age and growth

In a study on the population structure and growth of *Rhabdosargus holubi* in the West Kleinemonde estuary from 1971-1973, Blaber (1974) calculated the growth of *L. amia* for comparative purposes. With the mouth of the estuary closed during this time, it was possible to calculate the growth rate of *L. amia* from length frequency data. The study showed that in the period from January to July 1971 the increase in the modal size of *L. amia* was from 90-200 mm SL (~18 mm.month^{-1}) (Blaber, 1974). Smale and Kok (1983), looking at the monthly length frequency distribution of *L. amia* in the Knysna estuary, calculated a slightly faster growth rate of *L. amia* i.e. from November to June, the modal progression was determined to be between 50-350 mm (~29 mm.month^{-1}).

Van der Elst *et al*. (1993) were first to age *L. amia* from South African waters and accomplished this by means of counting growth rings in whole sagittal otoliths. In this study *L. amia* was found to undergo rapid growth and L_∞ was calculated as 940 mm FL, although the largest specimen sampled was 1130 mm FL. Potts *et al*. (2008), off the southern Angolan coast, also showed *L. amia* to undergo rapid growth (K = 0.22 year^{-1}) and calculated L_∞ as 1 135 mm FL. The largest *L. amia* sampled by Potts *et al*. (2008) was 1190 mm FL (26, 2 kg), with a maximum age of 11 years, whereas the maximum age recorded by van der Elst *et al*. (1993) was 9 years.

Day *et al*. (1981) suggested *L. amia* reached a maximum weight of 25 kg at a length of 1700 mm. Questionably, Boubacar *et al*. (1999) and Heemstra and Heemstra (2004) suggested that *L. amia* could obtain a much larger length and weight (i.e. 2 000 mm and 50 kg). However, with the South African angling record for *L. amia* currently at 32, 2 kg (~1 500 mm FL) and the spearfishing record at 31, 2 kg (van der Elst, 1988), the maximum length is more likely to be ~1 800 mm FL (Smith and Heemstra, 1986).

Stock assessment

The only previous attempt to assess the stock status of *L. amia* in South African waters was carried out by van der Elst *et al*. (1993). *CPUE* data, from rock and surf angling tournaments held in KZN between 1957 and 1991, showed considerable fluctuations, but no obvious trends could be identified. A total mortality (Z) of 0.55 year^{-1} was determined using the slope of the descending limb of the catch curve. Fishing mortality (F) was calculated at 0.17 year^{-1} using tag-recapture data from the ORI/WWF-SA Tagging Project and a natural mortality (M) of 0.37 year^{-1} was calculated using Pauly's (1980) empirical equation. Using these mortality estimates yield-per-recruit (*YPR*) analysis was undertaken with $F_{0.1}$ estimated at 0.7 year^{-1} and when compared to an unfished situation the F_{SB50} (the reduction of spawning biomass by 50%) was at a fishing mortality of F = 0.66 year^{-1}. As the F value for the period 1957-1991 was far less than the calculated $F_{0.1}$ and F_{SB50} values, it was concluded that *L. amia* was not over-exploited. The rapid growth rate and relatively early attainment of sexual maturity was seen as advantageous in maintaining fishing pressure placed on *L. amia*. In addition, the comparatively low annual catch was perceived as another contributor to the lack of concern on the status of *L. amia*.

1.2 A description of the *Lichia amia* fishery in South Africa

Linefishing is defined as the use of hooks and line, excluding set longlines, to catch fish (van der Elst and Adkin, 1991). The South African linefishery is made up of commercial, recreational and subsistence components. This multi-user fishery is large and exploits over 200 fish species of which approximately 95 species are economically important (Griffiths *et al*., 1999). With no commercial exploitation of *L. amia* permitted throughout South Africa, *L. amia* is primarily targeted by the recreational linefishery.

As an open access fishery, South Africa's recreational fishery is large with an estimated 500 000 participants in 1996 (Brouwer *et al*., 1997; Mann *et al*., 1997; McGrath *et al*., 1997; Sauer *et al*., 1997; Mann, 2000; Mann *et al*., 2003). This component of the South African linefishery comprises four distinct sectors, i.e. shore-angling, skiboat fishing (marine), light-tackle boat fishing (predominantly estuarine) and spear-fishing. Furthermore, the above sectors comprise two definitive elements: formal organised competition angling and non-competitive social angling (van der Elst, 1989; Pradervand and Govender, 1999). Van der Elst and Adkin (1991), and Mann (2000) highlight the importance of the marine recreational fishery in meeting the recreational needs of many South Africans. McGrath *et al*. (1997) demonstrated that sport and recreation is a major reason for both recreational shore and skiboat fishing trips along the whole of the South African coast throughout all income brackets. According to van der Elst (1989) 15% of coastal residents fish in the sea regularly, while there is at least one angler in every four urban households. In a more recent evaluation of recreational fishing in South Africa, Leibold and van Zyl (2008) estimated the economic impact of the marine recreational fishery (the measure of change within the economy due to marine recreational fishery including purchases, supplies, materials, jobs, fuel etc) to be ~R 9.3 billion per annum.

As a popular gamefish *L. amia* is heavily targeted by all sectors of South Africa's recreational linefishery (van der Elst *et al*., 1993). Management of *L. amia* is enforced through a combination of regulations including decommercialization (no sale), a daily bag limit and a minimum size limit. Table 1.1 illustrates the history of management measures implemented for *L. amia* in South African waters. All lengths are TL measured in a straight line from the tip of the snout to the extreme end of the tail.

Table 1.1: Regulations for *Lichia amia* in South Africa.

Year	Regulations	Act
1973	Min. size (380 mm) Bag limit (5)	Sea Fishery Act No. 58 of 1973
1974	Min. size (700 mm) Bag limit (5)	Natal Conservation Ordinance (Ordinance No. 15 of 1974) – KZN only
1988	Min. size (700 mm) Bag limit (5) No sale	Sea Fishery Act No. 12 of 1988
1998	Min. size (700 mm) Bag limit (5) No sale	Marine Living Resources Act No. 18 of 1998
2005	Min. size (700 mm) Bag limit (2) No sale	Marine Living Resources Act No. 18 of 1998

1.3 Aims and Objectives of this study

Despite numerous amendments to the Sea Fishery Act and the implementation of a comprehensive suite of national management regulations designed to limit catch and effort in 1985, and the subsequent revision of these in 1992, many South African linefish species have been over-exploited (Griffiths, 2000). There has been a significant change in the species composition of catches and a gradual decline in *CPUE* along the coast of South Africa (van der Elst and Adkin, 1988; van der Elst and de Freitas, 1988; van der Elst, 1989; Bennett, 1991; Griffiths, 1997a; Attwood and Farquhar, 1999; Penney *et al*., 1999; Griffiths, 2000). Consequently, in response to the failure of previous management frameworks to generate realistic regulations and to fulfil the requirements of the Marine Living Resources Act (No. 18 of 1998), a new management protocol, the Linefish Management Protocol (LMP), was drafted in 1999 (Griffiths *et al*., 1999). The LMP lays out regulations for South Africa’s linefishery based on objectives and quantifiable reference points, and is designed to execute management plans for each important fish species through a predetermined cycle of monitoring, assessment and revision of management regulations (Griffiths *et al*., 1999). Other than a recent study on *L. amia* off the southern Angolan coast (Potts *et al*., 2008) and a preliminary investigation conducted by the ORI in 1992 into the age, growth and stock status of *L. amia* (van der Elst *et al*., 1993), relatively little research has been undertaken on this species in

South African waters. Therefore, due to its popularity as a gamefish to all sectors of the recreational fishery, reviewing the status of the *L. amia* stock and revising current management regulations according to the LMP is essential to ensure its future sustainable use.

Furthermore, the limited geographic range of *L. amia* and the degradation of many estuaries that function as important nurseries for this species, have aroused concern about the stock status of the South African population. Considering the value of *L. amia*, both in terms of its ecological function as an apex predator as well as its socio-economic importance to the recreational fishery, and the need to provide a scientific basis for its management, a comprehensive stock assessment is required to determine its current status. The focus of this study is therefore to review the biology and stock status of *L. amia* off the South African coast.

The specific aims and objectives of this study are:

1. To review the biology of *L. amia* as found in literature.
2. To assess the trends in catch per unit effort (*CPUE*) and catch composition of *L. amia* in the KZN marine recreational linefishery.
3. To determine the movement behaviour of *L. amia* through the analysis of tag-recapture data.
4. To determine the age and growth of *L. amia* both through the analysis of tag-recapture data and by assessment of growth rings in whole otoliths.
5. To assess the stock status of *L. amia* using tag-recapture models, per-recruit models and *CPUE* data to determine biological reference points and stock status indicators.
6. To model various management options in order to provide a scientific basis for the management of this species that will ensure future sustainable use.

CHAPTER 2

Assessment of the *Lichia amia* fishery in KwaZulu-Natal

2.1 Introduction

South Africa's marine recreational linefishery is a large, licence-controlled fishery, comprising a number of distinct sectors (i.e. shore angling, marine skiboat fishing, estuarine light-tackle boat fishing and spearfishing) and, with a wide range of different target species, it can be considered a multi-user, multi-species fishery. Shore angling by means of hook and line is a popular form of marine resource use in South Africa (Pradervand and Baird, 2002) and is considered one of the most popular methods of marine angling around the world (Hickley and Thompkins, 1998). Shore angling is accessible to all sectors of South Africa's society and is of great importance to thousands of people (McGrath *et al*., 1997; Singh, 2004). During the National Marine Linefish Survey (1994-1996) the management and participation of each sector of South Africa's linefishery was evaluated (Brouwer *et al*., 1997; Lamberth *et al*., 1997; Mann *et al*., 1997; McGrath *et al*., 1997; Sauer *et al*., 1997). McGrath *et al*. (1997) determined approximately 412 000 anglers take part in the shore fishery and accounted for an annual catch of about 4.5 million fish weighing approximately 3 000 tons (Brouwer *et al*., 1997). Recreational marine boat angling in South Africa takes place from a range of different vessel types from small, single-seater paddle-craft and jet-skis to large harbour-based charter vessels >10m in length. The most popular vessel type used in South Africa is the skiboat described by Penney *et al*. (1999). Boat anglers can target different types of fish depending on the tackle and method used. So-called "bottom-fish" and pelagic gamefish are the two most important groups of fish targeted. The South African marine recreational boat-based fishery has an estimated 3 500 boats and 12 800 anglers participating in the fishery (Sauer *et al*., 1997). In comparison to the above-mentioned fisheries, spearfishing involves using a diving mask, snorkel, fins and a rubber propelled spear to shoot selected fish species (Mann *et al*., 1997) and can take place from the shore (swimming out) or from a boat. This is the smallest sector of the South African linefishery comprising about 7 000 participants with a total annual catch of approximately 400 tons (Mann *et al*., 1997).

Monitoring catches of linefish in South Africa's marine recreational linefishery has been made possible through the establishment of the National Marine Linefish System (NMLS) in 1984. The

NMLS is a long-term catch and effort database that permits the efficient capture, storage and analysis of catch and effort data from South Africa's commercial and recreational linefishery (Penney, 1993; van der Elst and Penney, 1994; Pradervand and Govender, 1999). The database was created between 1983-1985 and was developed out of the need to combine and compare recreational data on database systems developed in KZN by the Oceanographic Research Institute (ORI), and data from commercial linefisheries on systems developed by Sea Fisheries (now Marine and Coastal Management – MCM) (Penney, 1993). Since the inception of the NMLS, staff at the ORI, MCM, and Ezemvelo KwaZulu-Natal Wildlife (EKZNW, formally known as the Natal Parks Board), have been involved in the collection and analysis of long-term catch and effort data from different sectors of the recreational linefishery in KZN (Pradervand and Govender, 1999).

The flexibility of the NMLS in capturing catch and effort data is a key function as it caters for all sectors of the recreational linefishery and has room for the addition of newly developed data types (Penney, 1993). Data from each facet of each sector of the recreational linefishery, i.e. the competitive (organised competitive angling) and non-competitive (social angling) elements for shore angling, skiboat fishing and spearfishing are incorporated through different data collection methods and entered into separate databases (van der Elst and Adkin, 1988; Pradervand and Govender, 1999). Being flexible, catch and effort data can be captured on the NMLS as long as a date, locality, fish species, an index of catch (weight or number) and effort (e.g. angler hours) is available (van der Elst and Penney, 1994). The majority of recreational catch and effort data captured onto the NMLS come from KZN.

Although the NMLS is a valuable source of long-term catch and effort data, there are a number of biases associated with these data including sample and non-sample biases (Mann-Lang, 1996). Sample biases include temporal bias, spatial bias, mis-identification of fish species, incorrect weights, exaggeration and under-reporting of catches in voluntary and observer-based data. For example, Pradervand (2007) highlighted the spatial and temporal bias caused by inconsistent patrol distances and hours on patrol. With 75% of EKZNW shore patrols performed between 6 am and 12 pm, the majority of anglers and fish caught in the afternoon and evenings have been excluded from shore patrols (Pradervand, 2007). Non-sample biases include targeting of certain fish species by anglers, especially during fishing competitions, resulting in a low catch rate of other species rather than an actual low quantity of fish (Mann-Lang, 1996).

Lichia amia is heavily targeted by all sectors of South Africa's marine recreational linefishery (van der Elst *et al*., 1993). As it has been categorised as a "recreational species" it is illegal for commercial anglers to catch and sell *L. amia*. The popularity of *L. amia* as a game fish to all sectors of the recreational fishery and a perceived decline in abundance has contributed to the concern over the status of *L. amia* in South African waters (van der Elst *et al*., 1993). The NMLS is the only province-wide, long-term data series available for assessing catch and effort trends in KZN's marine recreational fishery (Pradervand, 2007). A number of studies have focused on using NMLS data to assess trends in various components of the KZN marine recreational linefishery (Penney *et al*., 1999; Singh, 2004; Pradervand *et al.*, 2007a; Pradervand, 2007). However, with the large scope of most of these studies, little mention has been given to the specific trends in catch and effort of *L. amia*. This chapter assesses the trends in catch composition and catch per unit effort (*CPUE*) of *L. amia* over a 22-year period (1985-2006) in the KZN marine recreational linefishery on a zonal, regional and provincial basis utilising data extracted from the NMLS. In addition to the NMLS, a relatively new monitoring system was implemented in KZN during 2004 to monitor boat-launching effort (Pradervand *et al*., 2005). Known as the Boat Launch Site Monitoring System (BLSMS), these data were also integrated to provide a further source of information on trends in catches of *L. amia* in KZN.

2.2 Materials and methods

Data sources and study area

Catch and effort data are collected by EKZNW in fifteen zones along the KZN coast (Table 2.1 and Figure 2.1). The collection methods for the various sectors of the KZN marine recreational linefishery include EKZNW shore patrols, fishing competition results submitted by angling clubs, voluntary catch cards and EKZNW skiboat inspections (Penney, 1993; Govender, 1995a). The main sources of data that were used in this study included shore patrols, skiboat inspections and spearfishing catch cards.

Table 2.1: Description of Ezemvelo KwaZulu-Natal Wildlife shore patrol zones.

Region	Zone	Code	Location	Length (km)	
Maputaland	Bhanga Nek	BN	(3 565) Maputo/R.S.A. Border - (3 620) Hulley Point	55	157
	Sodwana Bay	SD	(3 624) Dewitt's Bay - (3 665) Red Cliffs (N.Natal)	41	
	Cape Vidal	CV	(3 666) Ochre Hill - (3 727) Mission Rocks	61	
Zululand	St. Lucia	SL	(3 732) 3732 Km - (3 741) St Lucia estuary mouth	9	162
	Mapelane	MP	(3 742) St Lucia South Bank - (3 755) Cape St Lucia	13	
	Richards Bay	RB	(3 763) Barge Reef - (3 824) Mainhulyami Hill	61	
	Mtunzini	MT	(3 829) Umlalazi River - (3 857) Amatikulu River Mouth	28	
	Tugela	TG	(3 858) Matigulu Bluff - (3 909) Umhlali River	51	
Greater Durban	Ballito	BT	(3 910) Christmas Bay - (3 934) Umhloti River	24	93
	Durban Area	DB	(3 935) Umdloti Water Tower - (3 978) Isipingo	43	
	Kingsburgh	KB	(3 979) Tiger Rocks - (4 005) Ilfracombe	26	
South Coast	Scottburgh	SB	(4 006) Umkomaas Pipeline - (4 041) 4 041 Km	35	116
	Umtentweni	UT	(4 042) Mtwalume River - (4 077) Umzimkulu River	35	
	Uvongo	UV	(4 078) Port Shepstone - (4 098) Ramsgate	20	
	Trafalgar	TF	(4 099) Mbizana - (4 125) Transkei Border	26	

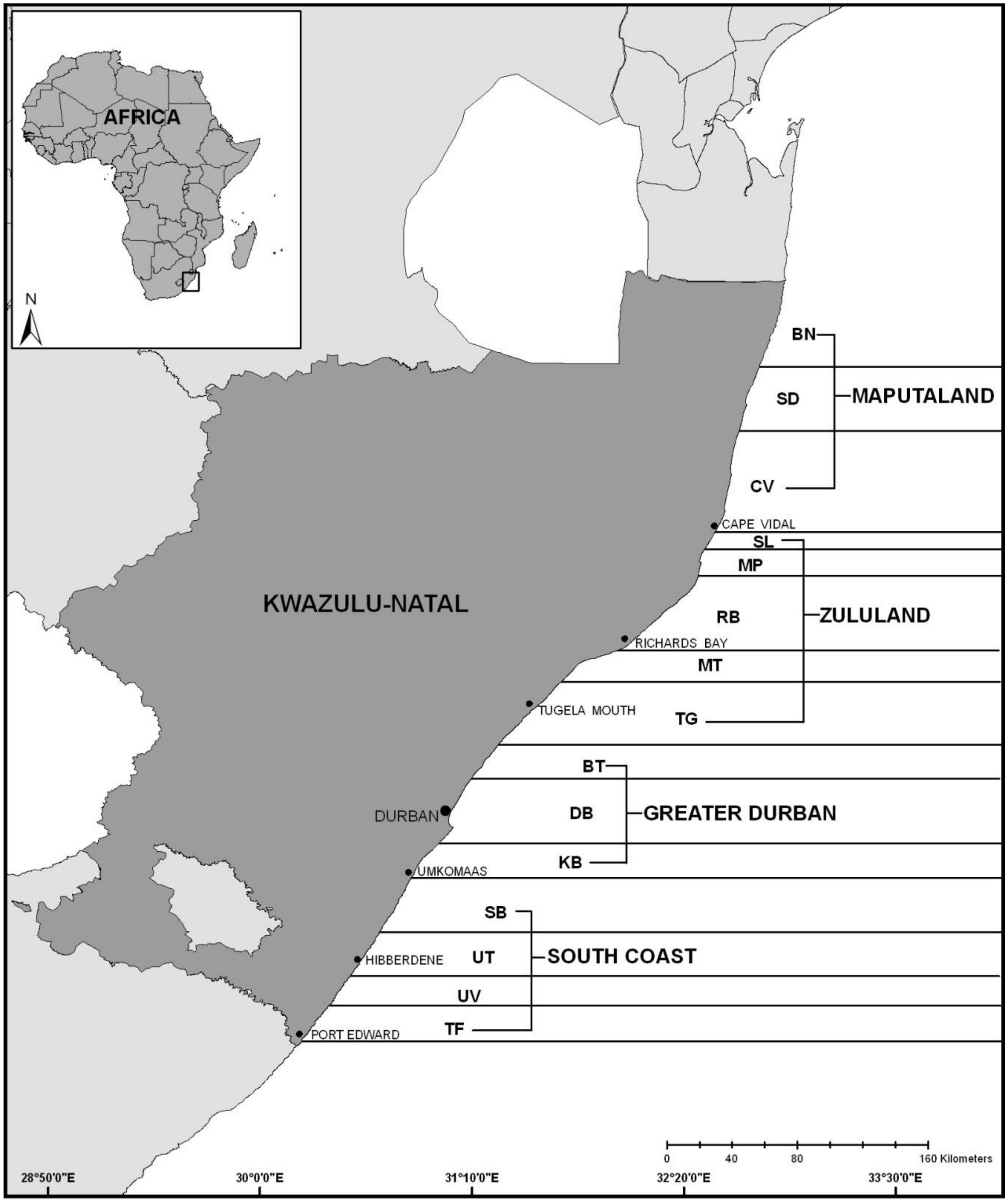


Figure 2.1: Ezemvelo KwaZulu-Natal Wildlife shore patrol zones along the KwaZulu-Natal coast.

Shore patrols

The main source of data for the marine recreational shore fishery were derived from the EKZNW shore patrols, who are mandated to undertake them as part of their fisheries monitoring obligations under the Marine Living Resources Act (No. 18 of 1998) (Pradervand, 2007). These patrols, which take place in the fifteen zones illustrated in Figure 2.1, provide a method for monitoring both competitive and non-competitive shore angling in KZN. Conducted mainly during daylight hours and on foot (van der Walt, 1995), these patrols are a form of roving creel survey in combination with law enforcement (e.g. ensuring adherence to fishery regulations). Data collected includes date, location, patrol distance (km), patrol hours, number and species of fish caught, number of anglers counted for the distance patrolled and distinction between marine or estuarine patrols.

Boat inspections

The collection of recreational boat angling data, through boat inspections, commenced in 1986 and has gradually replaced voluntarily submitted catch card data (Pradervand, ORI, *pers. comm.*). These inspections occur in the form of access point surveys and are conducted intermittently at all boat launch sites along the KZN coast. Data collected includes date, locality, time fished, number of crew, number of fish caught and estimated weights of each fish.

Catch cards

Catch cards are voluntarily submitted or collected at controlled access points. Information on the location and time fished, as well as the number and species of fish caught, is recorded on each card by the angler. As observed data (collected by a trained conservation officer) is generally considered better than voluntarily submitted catch card data (Mann-Lang, 1996), catch cards have been gradually phased out. Today only the estuarine boat fishery and the spearfishery are still monitored using catch cards in KZN.

Boat Launch Site Monitoring System (BLSMS)

The BLSMS is a relatively new monitoring system that was implemented in KZN in 2004. It is based on the completion of a boat launch register placed at all licensed boat launch sites along the KZN coast. Skippers must complete part of the register before going to sea (for safety reasons). On return, skippers must sign in and complete the register that includes a catch return of all fish caught for recreational anglers. These data form a complete data set as theoretically every outing and associated data are recorded. A drawback of the data is that it has only been recorded from 2004 onwards. There is also a relatively high level of non-compliance by skippers not completing the catch return data. For more information on the Boat Launch Site Monitoring System, see Celliers *et al*. (2004) and Pradervand *et al*. (2005, 2006, 2007b and 2007c).

Catch per unit effort (*CPUE*) and catch composition

Catch per unit effort (*CPUE*) refers to the number or weight of fish caught per unit of time fished (effort). *CPUE* is often used as an index of the abundance of a fish stock (Ricker, 1975; Hoggarth *et al*., 2006) but must be standardised to avoid bias. For the purposes of this study, *CPUE* was calculated as the number of fish caught per angler hour fished. However, in the case of the shore patrol data, where angler hours were not available for the entire data set due to computational constraints in the NMLS database (Pradervand, 2007), *CPUE* was expressed as the number of *L. amia* caught per angler inspected.

In order to illustrate the degree to which *L. amia* contributes to the total catch of the KZN marine recreational fishery over time, catches by number of *L. amia* were expressed on an annual basis as the percentage of the total catch composition for each sector of the fishery.

Shore fishery

Data derived from the EKZNW shore patrols from 1985-2006 (22 year period), were extracted from the NMLS and included information on location (zone locations given as a code, Table 2.1), date (month and year), number per species of fish caught, number of anglers inspected, number of patrols undertaken and total hours and distance (km) patrolled. Data were extracted on a zonal basis over the given time period. Seasonal and annual trends in patrolling effort (the total number of patrols conducted, total hours and distance patrolled) and number of anglers inspected are presented on a zonal, regional and provincial basis for the given time period. *CPUE* is presented as the number of fish caught per angler inspected (fish/angler insp.). The seasonal and annual trends in *CPUE* were expressed on a zonal, regional and provincial basis. As data were extracted on a zonal basis, and in order to reflect a regional and provincial scale (zones and regions illustrated in Table 2.1 and Figure 2.1), the data from each zone were summarised into the respective regions and for KZN as a whole.

Skiboat fishery

For the skiboat sector of the KZN marine recreational fishery, data derived from the boat inspections, as well as data from the BLSMS, were used to determine trends in catch and effort. The data extracted from the skiboat inspections (1985-2006) included the date, location (zone code), number of anglers, number of outings, number per species of fish caught and angler hours. These data were extracted from the NMLS on a provincial basis, because there was insufficient data to allow examination of trends on a zonal and/or regional basis. Inspection effort was expressed in terms of number of boat outings inspected and *CPUE* as the number of fish caught per angler hour (fish/angler/hr). Data from the BLSMS were extracted on a per launch site basis for the four year period (2004-2007) in which the BLSMS has been undertaken. This included data on location (launch site), date, number of crew (anglers), type and purpose for outing, and type and number of fish species retained. Effort was expressed as the total number of fishing outings recorded and *CPUE* as number of fish caught per angler hour (fish/angler/hr). Associated monthly trends (2004-2007) were presented on a provincial scale, with only those outings included that were recreational fishing outings and that had launch times, return times and number of crew recorded.

Spearfishery

Data derived from shore patrols, skiboat inspections and voluntary catch cards were used to determine catch and effort trends in the spearfishery during the given time period (1985-2006). The data extracted from the NMLS from the different sources were combined and included information on the date, location (zone code), number of spearfishers, number of outings, number per species of fish shot, and total hours fished. As for the skiboat fishery, data were extracted from the NMLS on a provincial basis due to the lack of sufficient data to illustrate trends on a zonal and/or regional basis. *CPUE* was expressed as the total number of fish caught per angler per hour (fish/angler/hr).

There are two summary systems available for the analysis of data on the NMLS, namely, a feedback summary system for participating anglers and a scientific system providing detailed analyses of catch, effort and *CPUE* data (Penney and van der Elst, 1988). For the purpose of this study, all data were extracted using the scientific system on an area-specific and per outing basis during the period 1985-2006 (22 years). Furthermore, for each fishery all temporal trends in *CPUE* were assessed by fitting linear least squares regressions to the overall annual *CPUE*. Measures of variability were not shown on associated graphs as this obscured observed trends in the data.

2.3 Results

Catch composition

In KZN from 1985-2006 a total catch of 2.8 million fish were recorded from all forms of data (Table 2.2). Of these only 10 422 were *L. amia* (0.37%). The percent contribution of *L. amia* to the total catch of the spearfishery is much higher than that contributed to the total catch of the recreational shore fishery and skiboat fishery (Table 2.2). When considering data from the BLSMS, which has only been captured for the past four years, only 664 *L. amia* were recorded caught by boat anglers out of a total recorded catch of 326 793 fish (0.20% contribution). Considering that, the BLSMS includes both skiboat anglers and spear fishers diving off a boat, this catch composition is similar to that observed in the NMLS data.

Table 2.2: Catch composition of *Lichia amia* for all sectors of the KwaZulu-Natal marine recreational linefishery from 1985-2006.

Data source	No. *L. amia*	Total catch	% composition
Shore fishery	8 498	2 390 745	0.36
Skiboat NMLS	484	414 492	0.12
Spearfishery	1 440	47 422	3.04
KZN	**10 422**	**2 852 659**	**0.37**

The percent contribution of *L. amia* to the overall total catch on an annual basis was presented for the shore fishery, skiboat fishery and spearfishery of KZN (Figure 2.2). The contribution of *L. amia* to all fisheries was highly variable between years. However, an overall decrease in the contribution of *L. amia* to all fisheries occurred from 1985-2006. Using linear least squares linear regression, the decreasing trend was only significant ($p<0.05$) for the spearfishery ($p = 0.0006$). Inter-fishery variations in the percent contribution occurred, although there was a close correlation between the contributions of *L. amia* to the total catch of each fishery during 1989 and 1997.

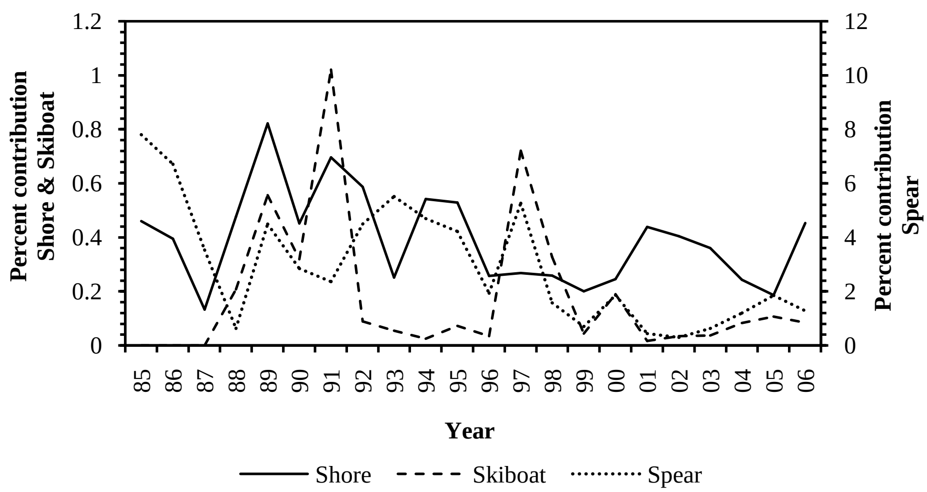


Figure 2.2: Percent contribution of *Lichia amia* to the total catch in all sectors of the KwaZulu-Natal marine recreational linefishery (1985-2006).

Shore fishery

The EKZNW shore patrol data extracted from the NMLS for the KZN shore fishery is illustrated in Table 2.3. On a provincial scale, during the given time period (1985-2006), just over 2.5 million anglers were inspected in KZN. Data were collected during 130 000 shore patrols that covered a total distance of just under 1 million km and took in excess of a quarter of a million hours.

The inter-regional distribution of patrols, in terms of the number of patrols conducted, as well as the hours spent on patrol, was not uniform ranging from <1-20% of the total sample (Table 2.3). The distance patrolled was, however, slightly more uniform. Coupled with this, the annual trends in the number of patrols undertaken, hours patrolled and number of anglers inspected, varied greatly within each region and between regions (Figure 2.3). The inter-annual variations in the number of patrols undertaken were, however, slightly less inconsistent in each region and between regions (Figure 2.3).

On a provincial level (KZN), there was a significant increase in the total patrolling effort and the number of anglers inspected over the given time period (Figure 2.4). Inter-annual variations in the number of anglers inspected and distance patrolled were extremely high during the first few years of undertaking shore patrols (1985-1993), after which they became slightly more consistent. Patrol hours and number of patrols were fairly uniform over the 22-year period.

Table 2.3: Total shore patrol effort and number of shore anglers inspected along the KwaZulu-Natal coast from 1985-2006.

Region	Zone	No. Patrols	%	Patrol Dist. (km)	%	Patrol Hrs.	%	No. Anglers Insp.	%
Maputaland	BN	2 883	2.23	49 365	6.06	2 688	0.74	12 253	0.48
	SD	4 850	3.74	36 624	4.50	10 037	2.76	21 347	0.83
	CV	13 095	10.11	59 974	7.37	59 391	16.31	219 964	8.59
Zululand	SL	7 260	5.60	31 664	3.89	17 877	4.91	275 978	10.78
	MP	5 298	4.09	20 037	2.46	12 880	3.54	71 834	2.80
	RB	5 118	3.95	58 057	7.13	5 801	1.59	61 655	2.41
	MT	2 503	1.93	15 579	1.91	4 111	1.13	15 961	0.62
	TG	9 025	6.97	68 488	8.41	22 093	6.07	146 239	5.71
Greater Durban	BT	10 124	7.82	93 954	11.54	41 457	11.39	270 353	10.56
	DB	25 890	19.99	91 200	11.20	50 996	14.01	514 599	20.09
	KB	7 434	5.74	63 031	7.74	25 108	6.90	302 507	11.81
South Coast	SB	8 944	6.90	63 811	7.84	31 660	8.70	147 887	5.77
	UT	9 242	7.13	68 568	8.42	25 673	7.05	181 179	7.07
	UV	7 646	5.90	38 886	4.78	21 250	5.84	170 181	6.64
	TF	10 221	7.89	54 959	6.75	33 042	9.08	149 283	5.83
KwaZulu-Natal		**129 533**		**814 198**		**364 064**		**2 561 220**	

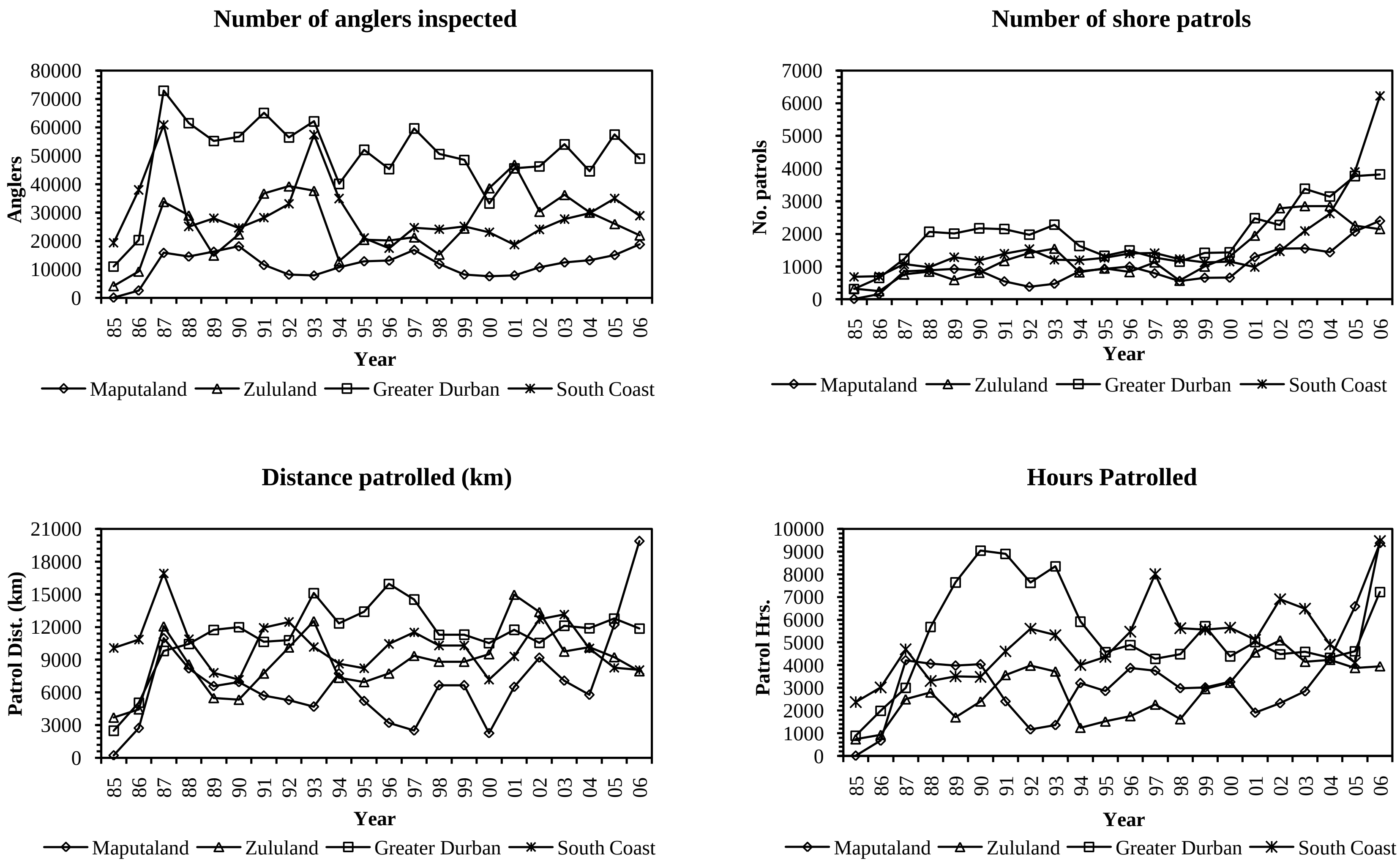


Figure 2.3: Annual trends in patrolling effort and number of anglers inspected per region of KwaZulu-Natal (1985-2006).

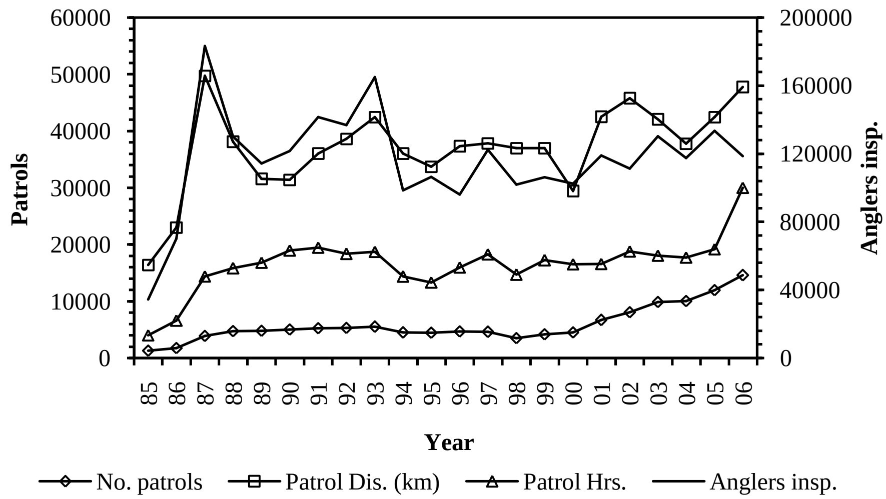


Figure 2.4: Annual trends in patrolling effort and number of anglers inspected along the KwaZulu-Natal coast (1985-2006).

The number of EKZNW shore patrols, the distance patrolled and the number of patrol hours undertaken each month was fairly constant in each region (except in the South Coast region which peaked in March and July) (Figure 2.5). Over the 22-year period (1985-2006), the average number of anglers inspected was higher during the winter months (July-August). All regions also showed a slight increase in December coinciding with annual holidays.

The number of patrols and total hours patrolled varied slightly on a monthly basis (Figure 2.6). As on a regional basis, the average number of anglers inspected was higher for KZN as a whole during the winter months (June-August) (Figure 2.6). During this time, the number of anglers inspected peaked in August (518 140 anglers). Lesser peaks in the number of anglers inspected occurred in January (93 168), April (150 224) and December (238 256), months that traditionally coincide with school holidays. Total distance patrolled was more variable, peaking mainly in December (80 042 km).

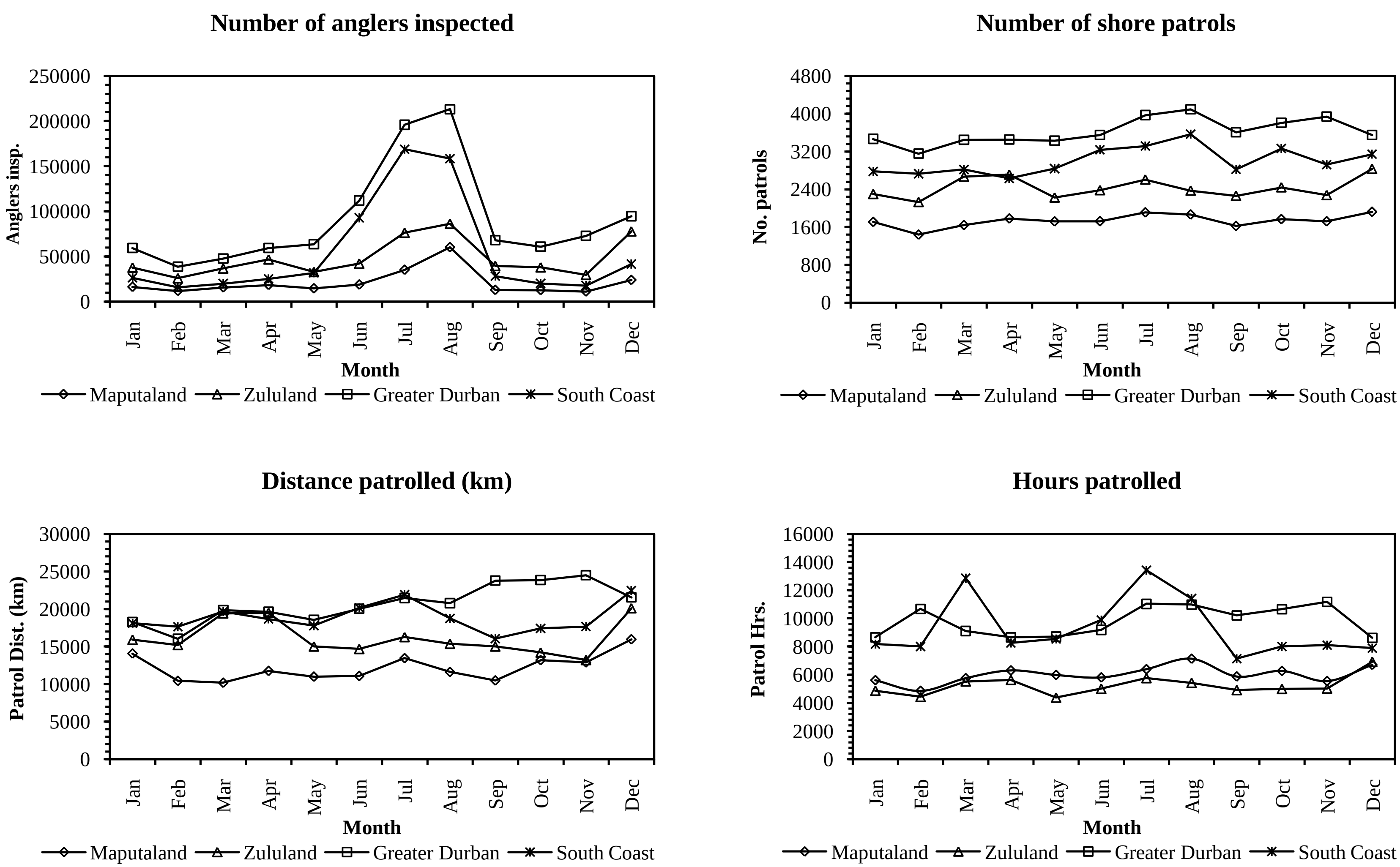


Figure 2.5: Monthly trends in patrolling effort and number of anglers inspected per region of KwaZulu-Natal (1985-2006).

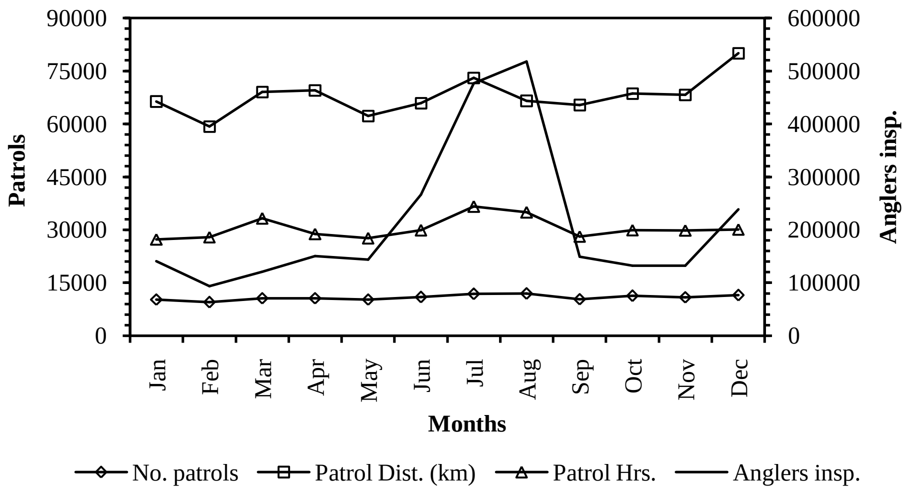


Figure 2.6: Monthly trends in patrolling effort and number of anglers inspected along the KwaZulu-Natal coast (1985-2006).

A total of 8 498 *L. amia* were caught by the anglers inspected (Table 2.4). The majority of these fish were caught in the Greater Durban region (47%), while the remaining three regions, Zululand, South Coast and Maputaland, contributed to a lesser degree to the total number of *L. amia* caught (25, 24 and 3% correspondingly) (Table 2.4). There was a large difference in the number of *L. amia* caught between zones, ranging from <1-24% of the total number of *L. amia* caught.

Table 2.4: Number of *Lichia amia* caught, on a regional and zonal scale, in the KwaZulu-Natal shore fishery (1985-2006).

Region	Zone	No. *L. amia*	%
Maputaland	BN	1	0.01
	SD	17	0.20
	CV	274	3.22
Zululand	SL	360	4.24
	MP	44	0.52
	RB	103	1.21
	MT	155	1.82
	TG	1 480	17.42
Greater Durban	BT	825	9.71
	DB	1 141	13.43
	KB	2 042	24.03
South Coast	SB	276	3.25
	UT	1 113	13.10
	UV	355	4.18
	TF	312	3.67
KwaZulu-Natal		**8 498**	

For KZN as a whole, the overall *CPUE* was calculated as 0.0033 (fish/angler insp.) (Table 2.5). On a regional basis, a higher *CPUE* was recorded in the middle reaches of the KZN coast, i.e. in the Zululand and Greater Durban region (Table 2.5). *CPUE* decreased slightly on the lower KZN coast (South Coast) and to a much greater degree on the northern KZN coast in the Maputaland region (Table 2.5). As with the number of *L. amia* caught and number of anglers inspected per zone, there was a high variability between the *CPUE* recorded for each zone.

Table 2.5: Zonal, regional and provincial *CPUE* (fish/angler insp.) for *Lichia amia* (1985-2006).

Region	Zone	***CPUE*** **(fish/angler insp.)**
Maputaland	BN	0.0001
	SD	0.0008
	CV	0.0013
Zululand	SL	0.0013
	MP	0.0006
	RB	0.0017
	MT	0.0097
	TG	0.0101
Greater Durban	BT	0.0031
	DB	0.0022
	KB	0.0068
South Coast	SB	0.0019
	UT	0.0061
	UV	0.0021
	TF	0.0021
KwaZulu-Natal		**0.0033**

As shown in Figure 2.7, the *CPUE* of *L. amia* has decreased in all regions in KZN, with the total number of *L. amia* caught also displaying a similar trend. The decreasing trend in the *CPUE* was, however, only significant (p<0.05) in the Greater Durban (p = 0.004) and Maputaland regions (p = 0.005). For KZN as a whole, a significant (p<0.05) decrease in the *CPUE* (p = 0.002) was recorded (Figure 2.7). Inter-annual variations along the KZN coast were also present and the highest *CPUE* was recorded in 1985 (0.01 fish/angler insp.) (Figure 2.7).

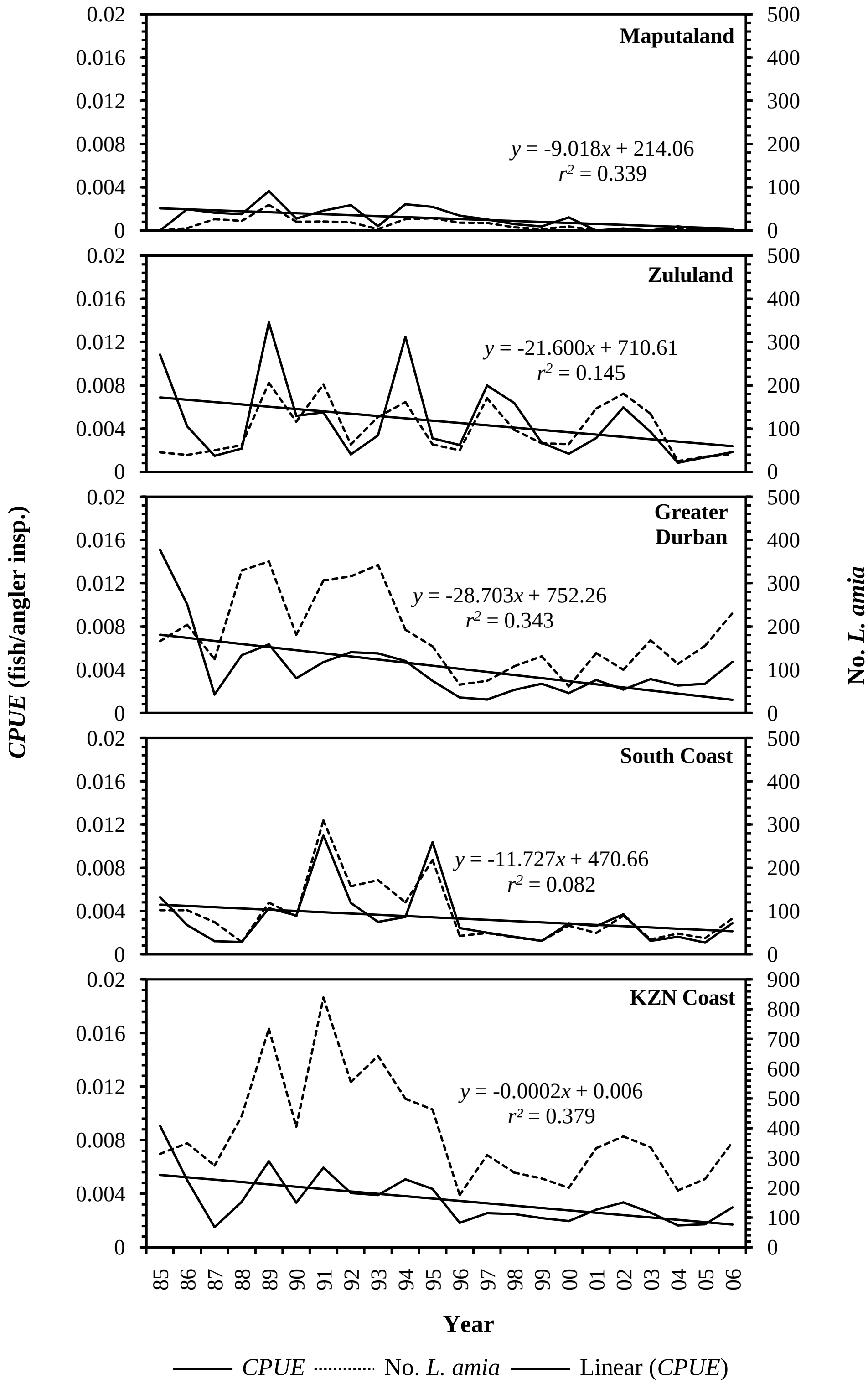


Figure 2.7: Annual trends in the *CPUE* (fish/angler inspected) and total number of *Lichia amia* caught per region and for the entire KwaZulu-Natal coast (1985-2006).

Seasonal trends in catches were evident with the number of *L. amia* caught increasing from April (autumn) for the South Coast, Greater Durban and Zululand regions, and in May further north along the KZN coast, i.e. in the Maputaland region (Figure 2.8). Catches in all regions peaked during the middle of winter (i.e. July/August). The number of *L. amia* caught then dropped off during the summer months (December-March). However, the Greater Durban and South Coast regions of KZN had bimodal peaks in abundance with higher numbers of *L. amia* caught during mid-winter and then again during the spring months (September-November).

For KZN as a whole, most *L. amia* were caught between May and November, and very few during summer months (December-March) (Figure 2.8). Although highest catches were recorded in June-August, *CPUE* is highest during September and October (Figure 2.8). There was a bimodal peak in *CPUE* in the South Coast region. This may reflect the migratory behaviour of *L. amia* with fish arriving in KZN in June and then returning to the Cape during spring once spawning is complete.

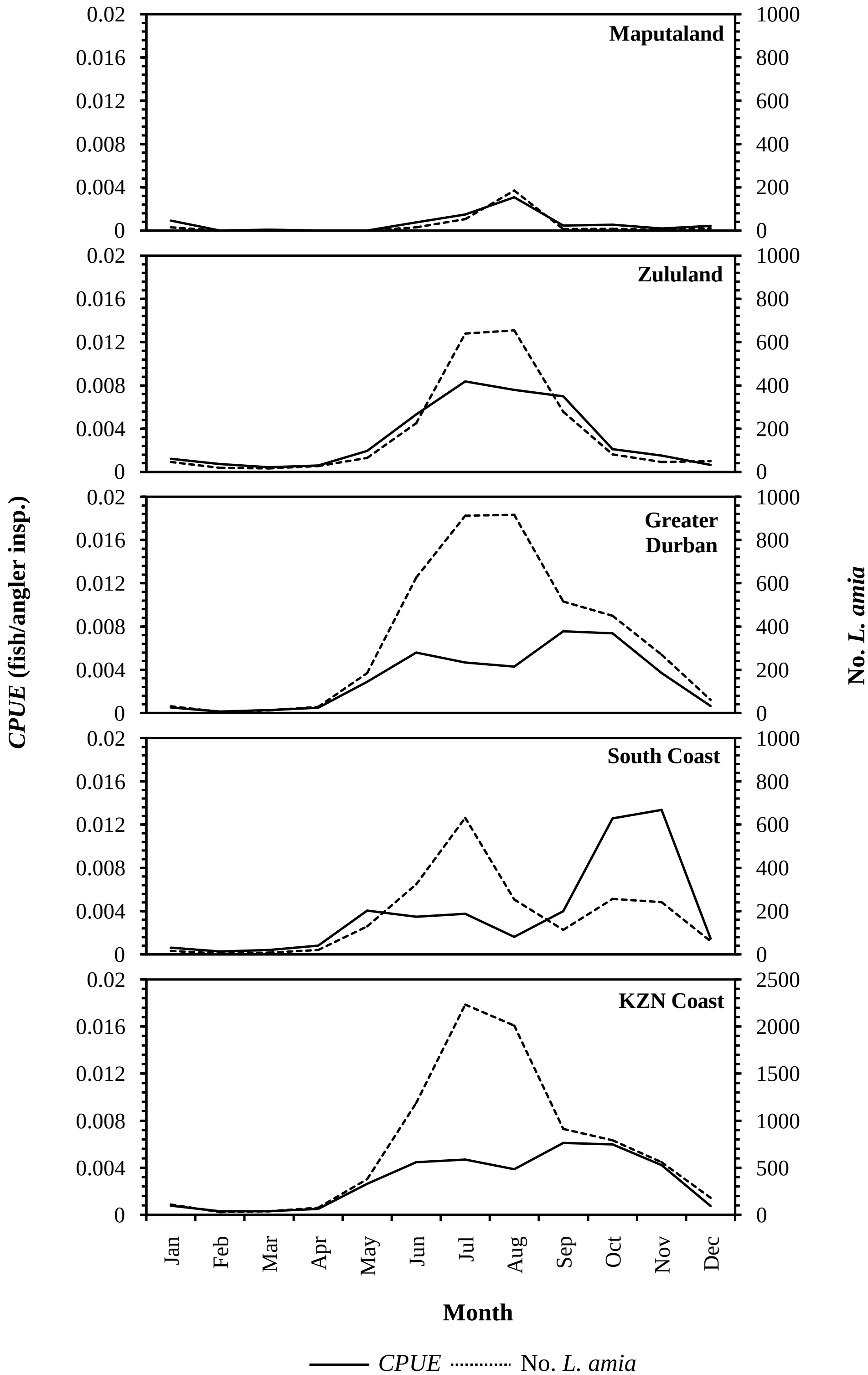


Figure 2.8: Monthly trends in the *CPUE* (fish/angler inspected) and total number of *Lichia amia* caught per region and for the entire KwaZulu-Natal coast (1985-2006).

Skiboat fishery

Boat inspections

A total of 56 719 boat inspections, incorporating 1 152 866 angler hours, were recorded from 1985-2006. Annual trends in the total number of boats inspected and angler hours fished from 1985-2006 are shown in Figure 2.9. There has been a significant increase in the number of boat inspections conducted and angler hours fished (which is linked to number of boats inspected) from 1985-2006.

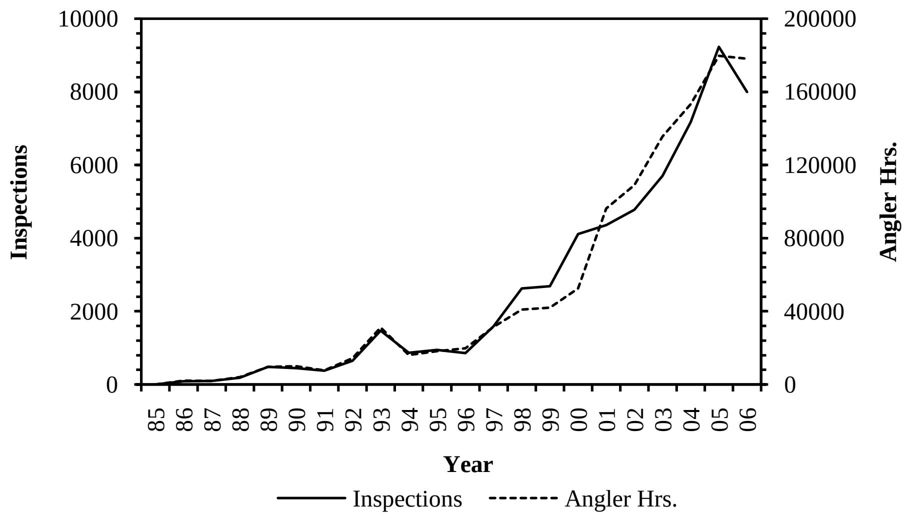


Figure 2.9: Annual trends in number of boat inspections conducted and angler hours fished at launch sites along the KwaZulu-Natal coast (1985-2006).

The majority of boat inspections were conducted during the warmer summer months (December-May), with the exception of a peak in July (Figure 2.10). The number of inspections was lowest from August-November, which is synonymous with the windy months of the year.

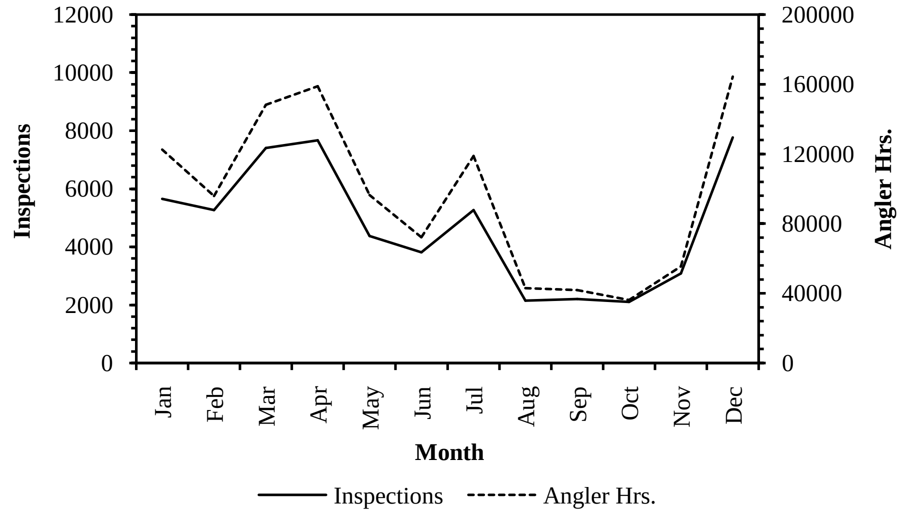


Figure 2.10: Monthly trends in number of boat inspections conducted and angler hours fished at launch sites along the KwaZulu-Natal coast (1985-2006).

In terms of catches of *L. amia*, the overall *CPUE* for the skiboat fishery was 0.0004 fish/angler/hr. Annual trends (1985-2006) in *CPUE* (fish/angler/hr) and the total number of *L. amia* caught based on skiboat inspections are illustrated in Figure 2.11. Although the total number of *L. amia* caught increased from 1985-2006, this was primarily due to the higher number of boat inspections conducted. The *CPUE* over the same period decreased (Figure 2.11), although this trend was not significant (p>0.05, p = 0.316). Both the *CPUE* and number of *L. amia* caught had high inter-annual fluctuations. Peaks in the number of *L. amia* recorded caught in 1989, 1991 and 1997 correlate with peaks in the number of *L. amia* caught in the shore fishery during the same years (Figure 2.7).

The seasonal trends in total number of *L. amia* caught and *CPUE* for the skiboat fishery are illustrated in Figure 2.12. The number of *L. amia* caught showed a similar trend to the *CPUE*. Both show increases from June onwards and decrease in November-December. Unlike the shore fishery where catches of *L. amia* peaked in July-August (Figure 2.8), the number of *L. amia* caught on skiboats peaked in October. *CPUE* was highest in October, similar to the shore fishery that peaked in September/October (Figure 2.8).

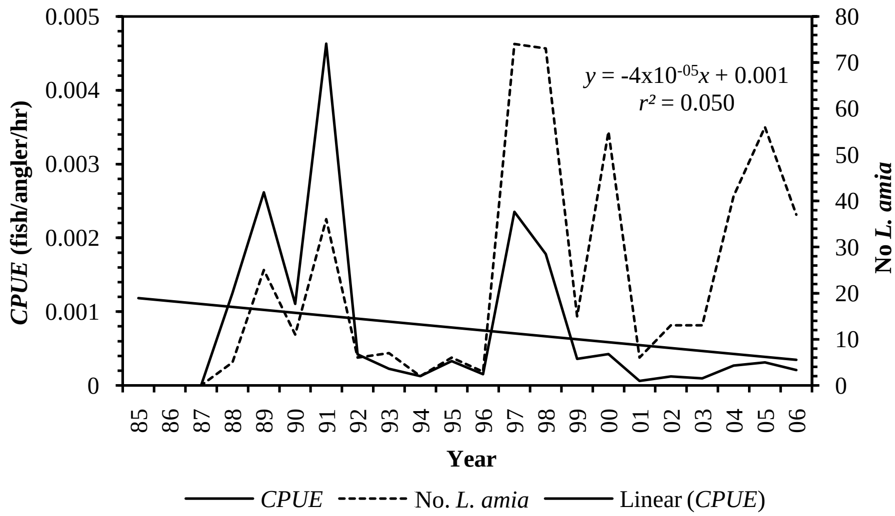


Figure 2.11: Annual trends in the *CPUE* (fish/angler/hr) and total number of *Lichia amia* caught in the skiboat fishery of KwaZulu-Natal (1985-2006).

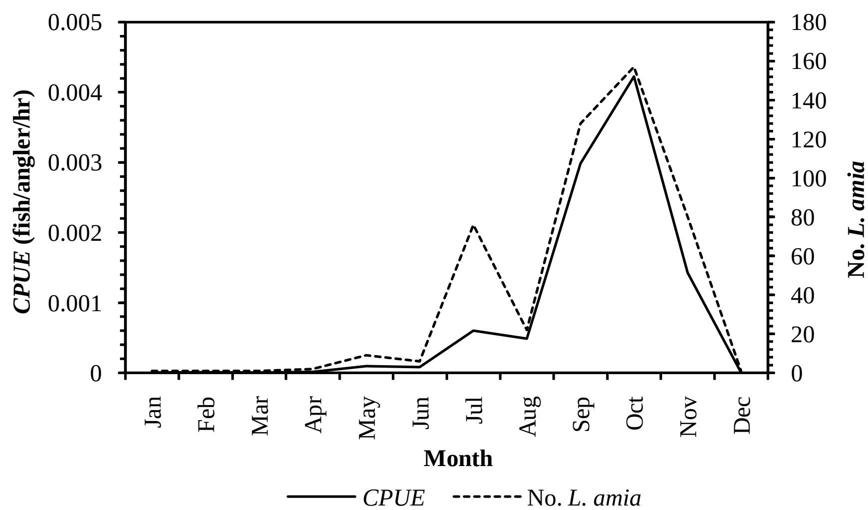


Figure 2.12: Monthly trends in the *CPUE* (fish/angler/hr) and total number of *Lichia amia* caught in the skiboat fishery of KwaZulu-Natal (1985-2006).

Boat Launch Site Monitoring System (BLSMS)

After filtering the available data, a total of 88 968 boat outings that indicated they were undertaking recreational fishing were recorded on the BLSMS from 2004-2007. The seasonal trends in the number of boat outings and angler hours from the BLSMS (Figure 2.13) were similar to the trends recorded from the NMLS boat inspections (Figure 2.10). The highest numbers of outings were recorded in summer (December-May) with the exception of July and the lowest numbers from August-November (Figure 2.13).

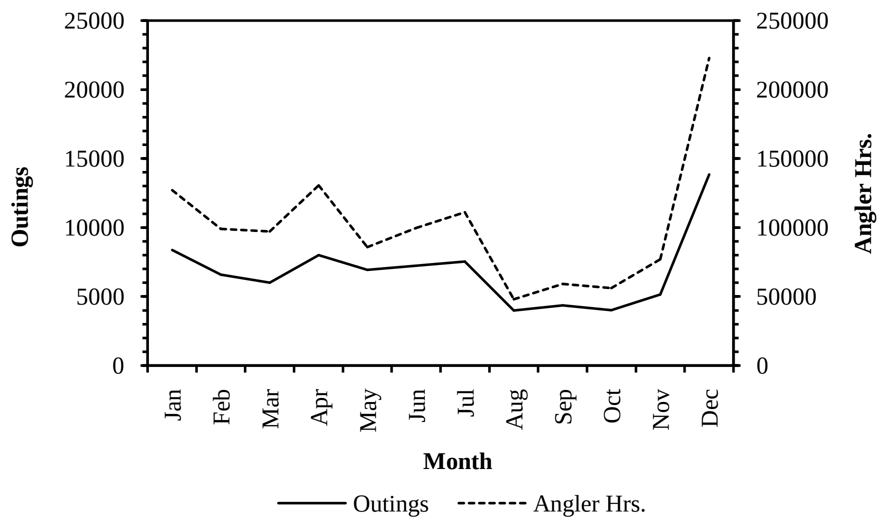


Figure 2.13: Monthly trends in number of boat outings and angler hours recorded on the BLSMS at launch sites along the KwaZulu-Natal coast (2004-2007).

The total *CPUE* using data extracted from the BLSMS was calculated as 0.0005 fish/angler/hr. Seasonal trends in the number of *L. amia* caught and *CPUE* (fish/angler/hr) for the data extracted from the BLSMS (Figure 2.14) were similar to the NMLS skiboat inspection data (Figure 2.12), i.e. the total number of *L. amia* caught and *CPUE* increased from May and peaked in October.

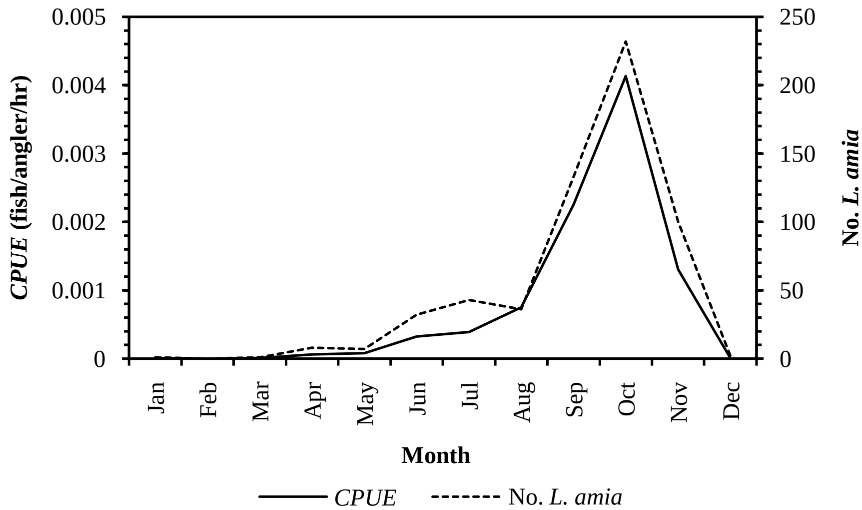


Figure 2.14: Monthly trends in the *CPUE* (fish/angler/hr) and total number of *Lichia amia* recorded caught on the BLSMS at launch sites along the KwaZulu-Natal (2004-2007).

Spearfishery

The total number of spearfisher outings recorded on the NMLS decreased from a peak in 1992/93 (Figure 2.15). Conversely, the number of angler hours recorded fluctuated between 1985 and 2006 with peaks in 1990, 1992, 1999 and 2004 (Figure 2.15). Seasonal trends in number of outings and angler hours were similar to the skiboat fishery with high effort recorded between December-May, with a peak in July and low effort from August-November (Figure 2.16).

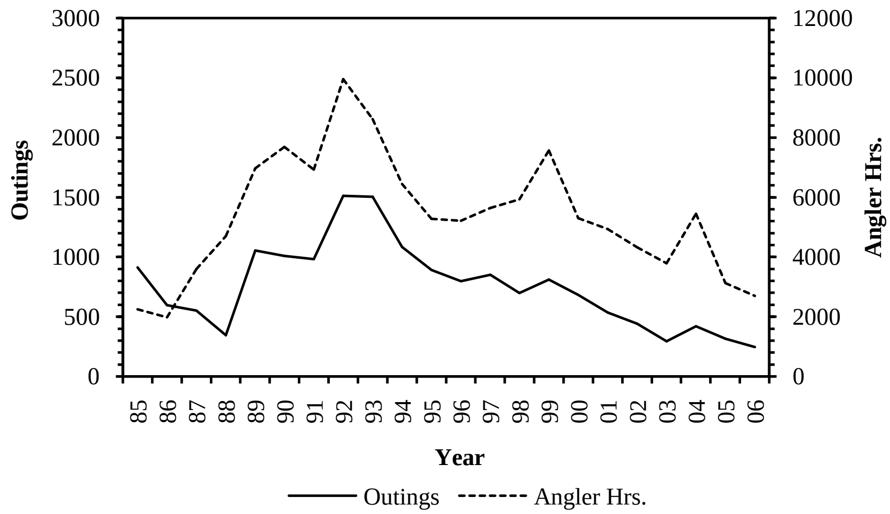


Figure 2.15: Annual trends in the number of outings inspected and angler hours for the spearfishery off KwaZulu-Natal (1985-2006).

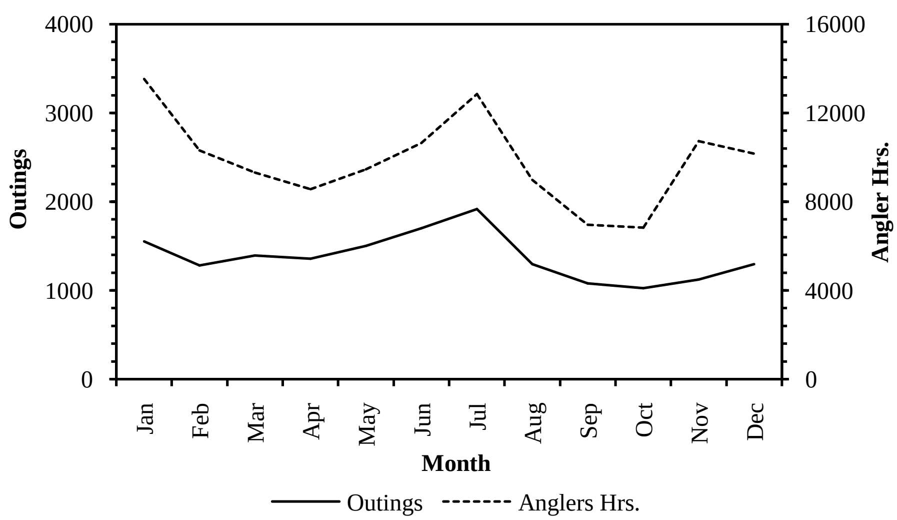


Figure 2.16: Monthly trends in the number of outings inspected and angler hours for the spearfishery off KwaZulu-Natal (1985-2006).

The *CPUE* (fish/angler/hr) and the total number of *L. amia* shot in the spearfishery showed a similar decreasing trend in KZN from 1985-2006 (Figure 2.17). The *CPUE* decreased significantly ($p<0.05$, $p = 0.0007$), similar to the shore (Figure 2.7) and skiboat fisheries (Figure 2.11). There was also an indication of a cyclical peak in the *CPUE* for *L. amia* in the spearfishery approximately every 3-4 years. Overall *CPUE* was calculated as 0.012 fish/angler/hour.

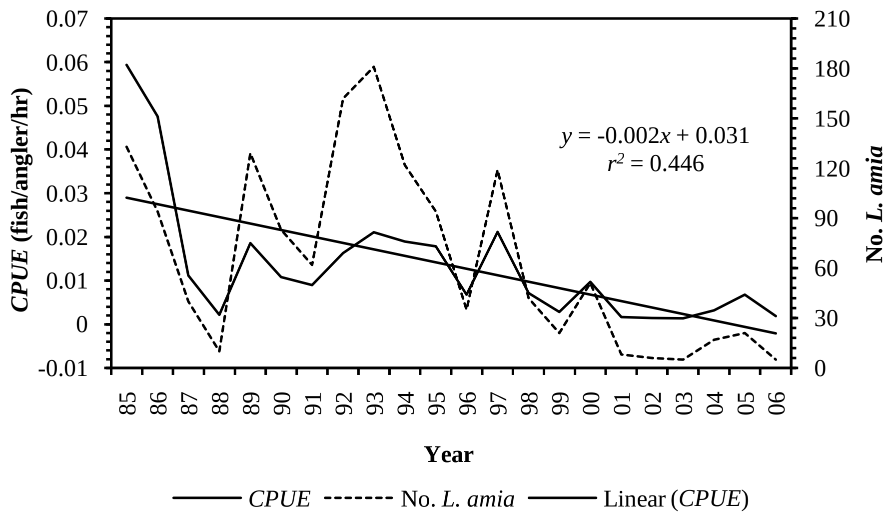


Figure 2.17: Annual trends in the *CPUE* (fish/angler/hr) and total number of *Lichia amia* shot in the KwaZulu-Natal spearfishery (1985-2006).

Seasonal trends in *CPUE* were very similar to the total number of *L. amia* shot (Figure 2.18). Similar to the other fishery sectors, the highest *CPUE* and total number of *L. amia* occurred in the winter and spring months (June-November), and was lowest during December-March. Total number of *L. amia* shot peaked in July similar to the shore fishery (Figure 2.8). Interestingly, *CPUE* was highest in July and remained more constant throughout the winter months into spring (June-November) than it did in the other two fishery sectors.

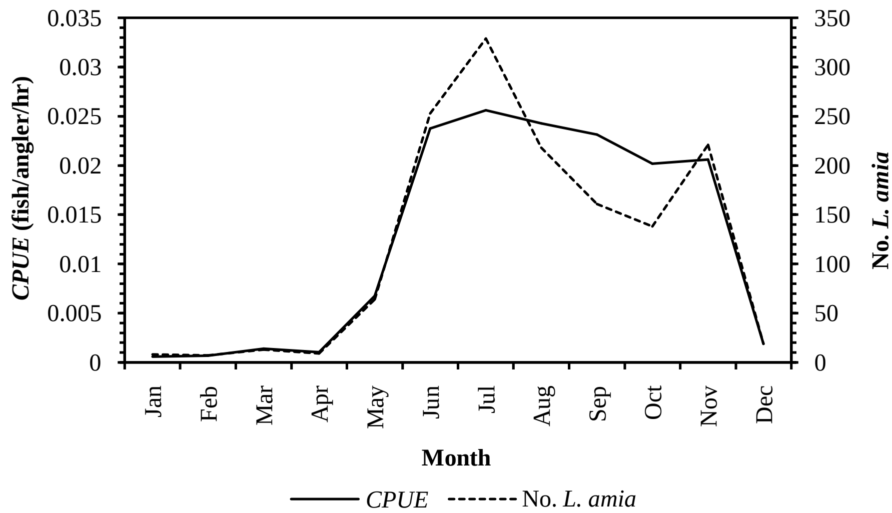


Figure 2.18: Monthly trends in the *CPUE* (fish/angler/hr) and total number of *Lichia amia* shot in the KwaZulu-Natal spearfishery (1985-2006).

2.4 Discussion

CPUE is often used as an index of the abundance of a fish stock (Ricker, 1975; Hoggarth *et al*., 2006). However, raw *CPUE* may not be proportional to the abundance over the entire exploitation history and geographic range of a species with many factors effecting catch rates, i.e. improved fishing techniques, species targeting, environmental factors and species population dynamics (Maunder *et al*., 2006). Thus, it is important that *CPUE* should be standardised to enable determination of trends over time. Standardised *CPUE* serves as an index of the state of a fishery, and is often considered one of the most important indicators for a fishery with a decrease in *CPUE* triggering management concerns (Hoggarth *et al*., 2006). South Africa's Linefish Management Protocol (LMP) recommends the use of such stock status indicators in the absence of a stock assessment (Griffiths *et al*., 1999). These indicators were set as a starting point for developing regulatory action, and incorporate corresponding conditions that advocate whether a reduction in catch and/or effort is necessary. These indicators include trends in the percent contribution to total catch and *CPUE*.

According to the LMP, a decrease greater than 75% in the proportion of *L. amia* in the total catch warrants a necessary decrease in fishing effort (Griffiths *et al*., 1999). The percent contribution of *L.*

amia to all KZN recreational fisheries decreased from 1985-2006. By taking the average contribution of *L. amia* to the total catch in the first five (1985-1989) and the last five years (2002-2006) under study, the percent difference provides a good indication of the decrease in the contribution of *L. amia* to the total catch along the KZN coast. From this analysis, the contribution of *L. amia* to the shore fishery has decreased by 28%, while it has decreased by 77 and 84% in the skiboat and spearfishery respectively.

In addition, the LMP states that *CPUE* would have to be less than 25% of a historical value or *CPUE* in an unfished protected area, for a reduction in effort to be necessary (Griffiths *et al*., 1999). From this study, *CPUE* calculated for *L. amia* decreased in each sector of the KZN marine recreational linefishery (1985-2006) with all trends significant ($p<0.05$) except for the skiboat fishery ($p>0.05$). Once again, the percent difference in the average *CPUE* between the first five years of data collection and the last five, gives an appropriate indication of the change in *CPUE* along the KZN coast. In the last five years (2002-2006), the average *CPUE* has declined by 52%, 90% and 93% in the shore, skiboat and spearfishery respectively when compared to the average *CPUE* during the first five years under study. Most fisheries do not have the luxury of comparing "pristine" conditions with present day conditions. Fortunately, recent work by Potts *et al*. (2008) on the largely unfished *L. amia* population off the southern Angolan coast provided an opportunity for comparison. Potts *et al*. (2008) calculated *CPUE* at 0.13 fish/angler/hour for *L. amia* in the Angolan shore fishery. This is much higher than the value calculated in this study of 0.0028 fish/angler/hour calculated for *L. amia* in the KZN shore fishery from 2002-2006, indicating a 98% decrease in *CPUE* (angler hours where recorded in the NMLS for the shore fishery from 2001 onwards). However, due to exclusive targeting of *L. amia* in the Potts' *et al*. (2008) study, these results are not strictly comparable with the values from this study. Nevertheless, it does give an indication of what the *CPUE* for *L. amia* could have been for the shore fishery prior to fishing along the KZN coast.

It could be argued that the decrease in *CPUE* seen in all sectors of the KZN recreational linefishery is due to a change in targeting and fishing techniques (Bennett, 1991; Bennett *et al*., 1994) rather than a decrease in abundance. However, as *L. amia* is an extremely popular gamefish, it is more likely that as catches of *L. amia* decreased, anglers adopted new techniques that improved efficiency in catching this species in an attempt to maintain and improve catches (Pradervand *et al*., 2007a). Technological advances in the shore fishery that would facilitate improved catches of *L. amia* are vast and include inter alia: graphite rods, better multiplier reels, thinner and stronger line (monofilament, fluorocarbon and braided line), improved exchange of information on local fish abundance (cellular telephones), improved and available means of weather forecasting and associated environmental conditions (internet), as well as an increased knowledge base on fishing techniques on how to target specific fish species through DVD's, TV programmes, internet and angler influence (Pradervand *et al*., 2007a). In particular, grapnel sinkers and non-return bait sliding rigs have allowed for more efficient "swimming" of live bait into deeper water from the shore. Live baits such as *Pomatomus saltatrix*, *Sarpa salpa* and mullet, are extremely successful in capturing *L. amia* in KZN. The sliding rig allows live bait to remain alive for longer and its simplicity allows for anglers even of basic levels of skill to use them. The non-return function of the sliding rig also allows anglers to fish with live baits in rougher, previously unfavourable conditions, all of which should contribute to improved catches of *L. amia*. With rapidly improving fishing techniques, even constant catch rates in a fishery can indicate a stock decline (Hoggarth *et al*., 2006). However, the reduction in the catch of *L. amia* in the KZN linefishery, despite the improvement in fishing tackle technology, suggests that the stock may have declined even more than the catch rates suggest.

In South Africa, management regulations have been implemented with the objective of regulating fishing mortality by means of effort control (Griffiths *et al*., 1999). As a result, trends in *CPUE* of a species can be altered through the implementation of a number of regulations. Management of *L. amia* has been enforced through a combination of regulations including decommercialization (no sale), a daily bag limit and a minimum size limit since 1973 (Chapter 1). The only recent change in the regulations for *L. amia* was the reduction in the bag limit in April 2005 (i.e. from 5 to 2 fish/angler/day). Therefore, although these management regulations may have limited the catch of *L. amia* over the period under study (1984-2006), they were not sufficient to prevent the decreasing trends in *CPUE* seen in each sector of the KZN fishery. With the recent reduction in the daily bag limit occurring as recently as April 2005, the short period since the implementation of this new regulation meant that there was little chance for any effect on the *CPUE* to have been detected.

Using catch composition and *CPUE* as stock status indicators, as set out by the LMP, shows that catches of *L. amia* have declined along the KZN coast and that there is an excess of fishing effort directed at this species. It is thus considered likely that the fishing effort has exceeded the sustainable capacity of *L. amia* and that a reduction in effort is necessary to allow the stock to rebuild. However, as mentioned, there are a number of intrinsic sampling and non-sampling biases in the NMLS and BLSMS data used in this chapter, which cannot be ignored. These include incomplete trip bias (as catch is inspected during some point of an angler outing rather than on completion of the outing) (Mann-Lang, 1996) and spatial bias with some regions having a higher patrolling effort than others (Pradervand, 2008). Temporal bias may affect the number of *L. amia* recorded caught, as the diel distribution of patrols was poorly dispersed with the majority of the patrols undertaken during the morning (6:00 - 12:00) (Pradervand, 2008). Poor completion of catch returns and misidentification of species may have contributed to underestimating *L. amia* catch. As patrols are conducted with the primary objective of compliance with data collection being a secondary objective, estimates of angler effort may be inflated during high periods of fishing activity as more patrols are undertaken during these times, particularly during the shad/elf (*Pomatomus saltatrix*) season (Mann-Lang, 1996).

Although this study acknowledges the intrinsic biases in the data used, and other factors that can influence *CPUE* trends, they are difficult to avoid and the decreasing trends in *CPUE* of *L. amia* observed in all sectors of KZN's marine recreational fishery should be regarded as a "red flag" by fishery managers. Furthermore, with such a comprehensive data set (22 years) for all the sectors of the KZN marine recreational fishery, this study provides a more accurate indication of actual catch trends compared to previous research undertaken on, or including, *L. amia* in South African waters (such as van der Elst *et al*., 1993; Mann *et al*., 1998). Nevertheless, it is acknowledged that trends in catch contribution and *CPUE* are merely indicators of stock abundance and where possible these trends should be confirmed by undertaking a more thorough stock assessment (Chapter 5).

CHAPTER 3
Tag and Recapture Assessment

3.1 Introduction

Considering that most of the *Lichia amia* stock within South African waters is found between Cape Point and Cape Vidal, they are considered to have a limited geographic distribution (van der Elst *et al*., 1993). The limited distribution of *L. amia* and the degradation of many estuaries that function as important nurseries for this species, have aroused concern about the stock status of the South African population (Chapter 1). Catch records and anecdotal information (Biden, 1948; Schoeman, 1978), as well as a preliminary study on *L. amia* (van der Elst *et al*., 1993), suggest that *L. amia* migrate seasonally. Clearly seasonal migration has an important bearing on the geographic abundance and thus availability of migrating *L. amia* to anglers, and should therefore be taken into account in a stock assessment.

Tag-recapture studies are one of the primary method used in determining migration rates and movement patterns of fish. Such studies can also be used to estimate dynamics of fish populations such as growth rate and fishing mortality (Quinn and Deriso, 1999; Kohler and Turner, 2001). Once a large number of fish are tagged and subsequently recaptured, associated temporal and spatial data allow one to provide a detailed analysis of movement and dispersal patterns (Childs, 2005). A simple method of using such data to illustrate movement patterns (e.g. time and direction) would be to draw arrows by date from the sites of release and recapture (Xiao, 1996).

In 1984 South Africa's nationwide linefish tagging project, the ORI/WWF-SA Tagging Project, was initiated by the Oceanographic Research Institute (ORI) (van der Elst and Bullen, 1993). This tagging project is aimed at promoting the voluntary tag and release of fish caught by conservation-conscious fishermen and women. By doing so, the critical scientific information needed to assist in research and conservation of linefish stocks in southern Africa is generated (van der Elst and Bullen, 1993). Between 1984 and 2006, a total of 205 267 fish comprising 348 species were tagged and released, whereas 10 756 (5.24%) were recaptured (Tagging News, 2007). *L. amia* have proved to be a popular species for tagging with a total of 6 587 tagged and released along the South African coast between 1984 and the end of 2006 (Tagging News, 2007). Moreover, *L. amia* have one of the higher recapture rates with 461 (7%) recaptured during this time (Tagging News, 2007).

Through the ORI/WWF-SA Tagging Project the tagging and recapture of *L. amia* has been well established, providing a long-term data set allowing for the analysis of the movement behaviour of this species. Bearing in mind the need to incorporate migration into the stock assessment of *L. amia*, in this chapter the movement behaviour of *L. amia* is assessed through the analysis of tag-recapture data. This analysis was undertaken through examining the seasonality of the *L. amia* migration and by means of Hilborn's (1990) general movement model.

3.2 Materials and methods

Tagging

Anglers who express an interest in being involved in the ORI/WWF-SA Tagging Project have to formally request permission. Membership is granted once the credibility of the angler is verified. Once accepted, members receive a tagging kit and an individual angler code, and are provided with an instruction manual and a list of priority species for tagging. On catching and tagging a fish, participating anglers are required to measure and record the fork length of each specimen, as well as the date and location of capture. Fish are tagged using a small plastic dart tag (Hallprint, Australia) and a hollow needle-like applicator. For teleosts, the tag is inserted into the muscle below the dorsal fin and the barb of the tag is locked behind one of the pterygiophores. On each tag, a thin transparent sheath covers a unique tag number and a return address. *L amia* are primarily tagged using type A- or D-tags. A-tags, which are 114 mm long and have a diameter of 1.6 mm, are used for larger fish, i.e. those greater than 600 mm FL (>3 kg). Type D-tags are similar in design to A-tags, however they are slightly shorter (85 mm long x 1.6 mm diameter) and are used for smaller fish between 300-600 mm FL (0.5-3 kg).

The data recorded for each tagged specimen are then sent via mail to the ORI on a pre-addressed tag card, where it is incorporated into the tagging database. Localities are converted into code numbers that correspond to the distance in kilometres from the northern border of Mozambique round to the northern border of Namibia (i.e. 1 – 8 082). When a fish is recaptured, the same information (FL, date, locality) is recorded with the unique tag number and sent to the ORI where it is once again incorporated into the tagging database.

Data extracted from the ORI/WWF-SA tagging database were used to present the total number of *L. amia* tagged and recaptured, per month and per year, for each region and province along the South African coast between Kosi Bay and Cape Point from 1984-2006. The locality codes for each region and province along the South African Coast between Kosi Bay and Cape Point are illustrated in Table 3.1. The Eastern and Western Cape are divided into regions as described by Bullen and Mann (2006) and those regions in KZN as described in Chapter 2.

Table 3.1: Locality codes for each region and province along the South African Coast between Kosi Bay and Cape Point (3 565 – 5 653).

Province	Region	Locality code	Locality names
KZN	Maputaland (MP)	3 565 – 3 727	Kosi Bay – Mission Rocks
	Zululand (ZL)	3 732 – 3 909	Cape Vidal – Umhlali River
	Greater Durban (GD)	3 910 – 4 005	Xmas Bay – Ilfracombe
	South Coast (SC)	4 006 – 4 125	Umkomaas Estuary – Umtamvuna River
Eastern Cape	Transkei (Trans.)	4 126 – 4 400	Mtentwana River– Kei River
	Border (Bor.)	4 403 – 4 546	Cape Morgan Light House – Fish River
	Lower Eastern Cape (LEC)	4 550 – 4 974	Little Fish Point – Robberg Point
Western Cape	Southern Cape (SCp)	4 976 – 5 268	Percys Bank – Cape Infanta
	Lower Western Cape (LWC)[1]	5 272 – 5 653	Infanta Light House – Cape Point

[1]LWC = rest of Western Cape as far as Cape Point (5 653)

In addition, the length frequencies of all *L. amia* tagged and recaptured were plotted per province along the South African coast. Unfortunately not all tagged and recaptured *L. amia* were measured and in some cases the length type measured (i.e. fork length or total length) was not indicated. In both cases, these data were discarded. Where length was measured as total length (TL) this was converted to FL using the TL/FL relationship for *L. amia* (Chapter 4).

Movement behaviour

Spatial and temporal movement

From all the tag-recapture data the following critical parameters were calculated: number of days at liberty (*dt*), the minimum displacement (*D*) in km between tag and recapture localities, and the rate of movement in terms of displacement per day at liberty (minimum speed = *D*/*dt*). Displacement and speed were considered minimal, as the route undertaken by a tagged and recaptured *L. amia* may not have been in a straight line from one location to another and, depending on the number of days at liberty, a fish may have moved a substantial distance but then have been recaptured in a similar locality to where it was originally tagged (Hussey *et al*., in press). The geographical orientation of the eastern seaboard of the South African coast is roughly northeast-southwest, thus minimum displacement of tagged *L. amia* were separated into net northerly and southerly movements (negative and positive latitudinal displacement respectively). The mean, minimum and maximum *D*, *dt* and speed (*D*/*dt*) were presented for northerly and southerly movements for all the tag-recapture data. Displacement (*D* in km) was then plotted against release length (mm FL) in order to illustrate any trend in the effect of length on this parameter.

In addition, the minimum, maximum and mean (with CV's) days at liberty (*dt*) of *L. amia* tagged were calculated in order to determine the effect of length on this parameter. For this, and in the absence of reliable maturity estimates or evidence indicating the first size at which the fish undertake their migration, *L. amia* were separated into size classes below (<587 mm FL) above (≥587 mm FL) the minimum size limit.

In order to determine seasonal and spatial movement patterns, all *L. amia* recaptured more than 365 days after tagging were excluded from statistical tests and plots described below, as these fish may have undertaken more than one return migration during their time at liberty.

Using the available length data (obtained as described above) the length frequency of the *L. amia* at liberty ≤365 days was plotted for each movement direction. Displacement was then divided into categories, namely ≤100 km, 101-200 km, and ≥201 km, and the tag and recapture locations of each *L. amia* were plotted against each corresponding month constrained within a 24-month period of liberty (as *dt* = ≤365 days). To simplify assessment of seasonality of movement, general summer (October-March) and winter (April-September) months were used (Hussey *et al*., in press).

For trends in the direction of movement to be analysed in relation to season and distance of displacement, data were separated into seasons (mentioned above). The month in which the fish was tagged defined the season of movement. In order to assess these trends, the non-parametric Kruskal-Wallis analysis of variance (nonparametric ANOVA or *H*-test with tied ranks) was employed, as the displacement data were not normally distributed and unequal in variance (Zar, 1999).

To determine whether a counter current inshore of the Agulhas Current assisted the northerly migration of *L. amia* in winter, a two-sample *t*-test (critical values selected at 95% CI) was used to compare those fish moving ≥201 km northwards in winter and those ≥201 km southwards in summer defined by the month in which they were tagged. The logarithmic transformation ($X' = \log[X + 1]$) of the speed data allowed the parametric *t*-test to be used. This allowed the testing of the hypothesis that a counter current inshore of the Agulhas Current assists the northward migration of certain fish species (Heydorn *et al*., 1978).

Tests for normality were undertaken using the Kolmogorov-Smirnov Test in Microsoft Excel (Guth, 2006) while variance was determined using the *f*-test for variance.

Movement model

The movement of *L. amia* was then quantified by evaluating the tag-recapture data using the maximum likelihood based method of Hilborn's (1990) general movement model. This model has proved very versatile for a number of authors (Quinn and Deriso, 1999; Aires-da-Silva *et al*., 2005; McDermott *et al*., 2005; Lukey *et al*., 2006). The framework of the model consists of three components:

1. A population dynamics and movement component, which includes natural mortality, fishing mortality and movement.
2. An observation component for recaptured fish, which estimates the number of fish recaptured in comparison to the actual number of recaptures.

3. A probability component to specify the likelihood of the observed recaptures, given the parameters from the population and observation models.

For the population dynamics and observation components of the model, the revisions by Xiao (1996) and Aires-da-Silva *et al*. (2005) were used. Xiao (1996) explicitly included terms for instantaneous natural mortality (M) and tag-shedding (λ). For consistency, Hilborn's (1990) and Xiao's (1996) notations were used with only minimal alterations. The population dynamics component of the model is written as:

$$\hat{N}_{i,a,t+1} = \sum_{j=1}^{n} \hat{N}_{i,j,t}\left(1 - F_{j,t}\right)e^{-(M+\lambda)}p_{j,a} + T_{i,a,t} \tag{3.1}$$

where: $\hat{\hat{N}}_{i,a,t}$ = the predicted number of tagged fish of group i present in area a at time t,

$F_{j,t}$ = fishing mortality in area j at time t,

$p_{j,a}$ = probability of movement from area j to area a (assumed to be constant),

$T_{i,a,t}$ = the number of fish tagged from group i in area a at time t.

Instead of considering additional tags as new tag groups, this approach also allows for recruitment into a tag group through the addition of newly tagged and released fish into that group at time t ($T_{i,a,t}$) (Aires-da-Silva *et al*., 2005). A tag group i, according to Hilborn (1990) and Xiao (1996), is a group of fish tagged in a spatio-temporal stratum but can be extended to include distinctive factors such as sex, size etc. For this reason, two tag groups released independently in two geographical areas along the South African coast were considered, namely the number of *L. amia* tagged in KZN ($T_{i,n,t}$) and in the Cape ($T_{i,c,t}$). This allowed the seasonal movement of *L. amia* between KZN and the Cape (Eastern and Western Cape as far as Cape Point) to be quantified. With a one year time step assumed in the model, the tag groups $T_{i,n,t}$ and $T_{i,c,t}$ were calculated as the number of *L. amia* tagged in each area during each year from 1984-2006.

Employing Pauly's (1980) empirical equation, van der Elst *et al*. (1993) obtained an instantaneous natural mortality (M) estimate of 0.4 year^{-1} for *L. amia* along the entire South African coast. This estimate of M for *L. amia* was used in the model. An estimate for tag-shedding and tag-associated mortality (λ) was not available as no double tagging or captive tagging of *L. amia* has been undertaken to date. Without a reliable estimate, and considering certain physical features and behavioural traits of *L. amia*, as well as field observations and recapture rates, tag-shedding and tag-associated mortality could be negligible and thus λ was assumed to be zero (see discussion below). The model was however, run with a range of λ values (0.1 to 0.4 year^{-1}) to see the effect of tag-shedding on the parameter estimates.

L. amia is a popular gamefish to tag and has a relatively high recapture rate (7%) (Tagging News, 2007). However, as they are also considered to be a prize trophy fish and valuable food source, a large proportion of *L. amia* are retained once captured. Consequently, relatively few tagged *L. amia* are re-released if recaptured. For this reason, if in Eq. 3.1 the fishing mortality was calculated as $F = qE$, it would represent a probability of capture and not necessarily the actual mortality rate as described in Hilborn's (1990) method (Aires-da-Silva *et al*., 2005). The true harvest (fishing mortality rate) in area *j* at time *t* would thus be derived from the product of the "capture rate" and the "killing rate" ($K_{j,t}$) that was calculated from the proportion of *L. amia* re-released once recaptured in area *j* at time *t*:

$$F_{j,t} = q_j E_{j,t} K_{j,t} \tag{3.2}$$

where q_j is the catchability coefficient in area *j* and $E_{j,t}$ is the fishing effort in area *j* at time *t*. By calculating $F_{j,t}$ in this manner, it was assumed that fishing mortality in area *j* was proportional to the fishing effort directed at *L. amia* in area *j*, which was calculated as:

$$E_{j,t} = \frac{No.\ anglers\ \ inspected}{Total\ \ km\ patrolled} \times \frac{No.\ L.amia\ \ counted}{Total\ \ fish\ counted} \tag{3.3}$$

where the product of the total fishing effort and the proportion of *L. amia* in the total catch, was assumed to be proportional to the fishing effort directed at *L. amia* (Butterworth *et al*., 1989).

The observation component of the model specifies the relationship between the observed recaptures and the expected tag recaptures in a specific area. An extra parameter was added to Hilborn's (1990) observation component of the movement model:

$$\hat{R}_{i,a,t} = \hat{N}_{i,a,t} q_a E_{a,t} \beta_{a,t} \tag{3.4}$$

where $\hat{R}_{i,a,t}$ is the expected number of tag recoveries from tag group *i* in area *a* at time *t* and $\beta_{a,t}$ (the added parameter) is the proportion of recaptures which are reported in a useable form. The non-reporting rate of tags was determined as 30% during the National Marine Linefish Survey conducted from 1994-1996 (B. Mann, ORI, unpublished data) and this meant β = 0.7. It was assumed that when tagged fish were recaptured, it was reported with a tag number, date and location of recapture, which is the basic data required for the tag recapture to be useable.

$P_{j,a}$ and q_j needed to be estimated in Equations 3.1, 3.2 and 3.4 and, according to Hilborn (1990) and Hilborn and Walters (1992), the sampling distribution of tag recoveries can be estimated by a Poisson distribution. A poisson distribution is a discrete distribution in which the probability density function generates actual probabilities of an observed event occurring in a set period (Haddon, 2001). Therefore, the probability of the expected number of tag recoveries ($\hat{R}_{i,a,t}$ t = 1...n) given the observed number of tagged recoveries ($R_{i,a,t}$) is:

$$P(R_{i,a,t}) = \frac{e^{-\hat{R}_{i,a,t}} \hat{R}_{i,a,t}^{R_{i,a,t}}}{R_{i,a,t}!} \tag{3.5}$$

$R_{i,a,t}$ is the actual observed number of tag recoveries reported (recaptures) of group *i* in area *a* at time *t* (i.e. each year). The log transformation of Eq. 3.5 then denotes the likelihood (L) of the number of recoveries being reported (Hilborn, 1990):

$$L(R_{i,a,t} | \hat{R}_{i,a,t}) = \frac{e^{-\hat{R}_{i,a,t}} \hat{R}_{i,a,t}^{R_{i,a,t}}}{R_{i,a,t}!} \tag{3.6}$$

The total likelihood function is then:

$$\prod_{i,a,t} \frac{e^{-\hat{R}_{i,a,t}} \hat{R}_{i,a,t}^{R_{i,a,t}}}{R_{i,a,t}!} \tag{3.7}$$

The model parameters are then estimated by minimizing the total negative log-likelihood:

$$\sum_{i,a,t} [\hat{R}_{i,a,t} - R_{i,a,t} \log(\hat{R}_{i,a,t})] \tag{3.8}$$

The different components of the model and the total negative log-likelihood (Eq. 3.8) were calculated in Microsoft Excel and were minimized using the optimisation routine SOLVER. The 95% CL for the estimated parameters were calculated using the likelihood profile in Poptools (Hood, 2008), an "add-in" for Microsoft Excel that facilitates analysis of population models. A sensitivity analysis was undertaken by running the model with different values of natural mortality (M year^{-1}, see below) and discrepancies in the expected recaptures from the observed values were examined using "deviance" (McCullagh and Nelder, 1989), as recommended by Hilborn (1990):

$$deviance_t = -2\left[L\left(R_{i,a,t}\middle|\hat{R}_{i,a,t}\right) - L\left(R_{i,a,t}\middle|R_{i,a,t}\right)\right] \tag{3.9}$$

The framework for the movement model involved seven steps with n and c selected as the indices for KZN and the Cape respectively:

1. Tag groups were identified separately namely, $T_{i,n,t}$ and $T_{i,c,t}$ which were the number of *L. amia* tagged each year (1984-2006) in KZN and in the Cape respectively;
2. Input parameters were then selected for KZN (q_n and $p_{n,c}$) and for the Cape (q_c and $p_{c,n}$). M was set at 0.4 year^{-1} for both areas;
3. The effort directed at *L. amia* in KZN ($E_{n,t}$) and in the Cape ($E_{c,t}$) was then calculated (Eq. 3.3), as well as the "killing rate" from the number of tagged fish re-released each year ($K_{n,t}$ and $K_{c,t}$);
4. Initial values of the fishing mortality (Eq. 3.2) and the predicted number of tagged fish (Eq. 3.1) in each area at time t were established after step 3 ($F_{n,t}$, $\hat{N}_{i,n,t}$ and $F_{c,t}$, $\hat{\hat{N}}_{i,c,t}$);
5. The total negative log-likelihood was then minimised using SOLVER estimating $F_{n,t}$, $\hat{N}_{i,n,t}$, $F_{c,t}$ and $\hat{N}_{i,c,t}$;
6. Observed and expected tag recoveries in KZN and the Cape were then plotted and deviance between the two calculated;
7. Sensitivity analysis was undertaken by re-running the model with M = 0.3 and 0.5 year^{-1}, this was done to test whether M was confounded with $p_{n,c}$ and $p_{c,n}$ (if so, as M increases $p_{n,c}$ and $p_{c,n}$ are expected to increase).

Assumptions made when undertaking the movement model included: (i) there was movement between KZN and the Cape that did not affect survival; (ii) mortality was only a function of the instantaneous annual fishing mortality and natural mortality rate. Furthermore, tagged fish were assumed to be fully mixed with the untagged population and that behaviour of tagged fish was the same as untagged fish (migration, chance of recapture and harvest rate), thus tagged individuals were assumed to be representative of the total population.

3.3 Results

Tagging

By December 2006, 6 456 *L. amia* had been tagged and 457 (7.08%) recaptured along the South African coast since 1985 (Table 3.2). Tagging and recaptures were not distributed equally along the South African coast (Figure 3.1). A total of 4 181 *L. amia* (65%) were tagged in the Eastern Cape, 1781 (28%) in the Western Cape and 491 (8%) in KZN. The highest number (51%) of recaptures also occurred in the Eastern Cape (n = 235), with 31% in KZN (n = 141), and the least in the Western Cape (n = 81 or 18%). The bordering LEC and SCp regions had the highest number of *L. amia* tagged with much fewer in the remaining regions (<9%). Similarly the highest number of *L. amia* were re-caught in these two regions with far fewer (<8%) in the remaining regions, with the exception of the GD region (Figure 3.1).

Although fewer *L. amia* were tagged and recaptured in KZN than in the Cape, the recapture rate in KZN was far higher (Table 3.2). Of the *L. amia* recaptured, the majority (66%) were recaptured within 12 months of release, 21% were recaptured within 24 months and the remainder (13%) >24 months at liberty (Figure 3.2).

Only 16% (n = 71) of the 457 *L. amia* recaptured were re-released. However, this value is probably higher as some anglers re-tag, recaptured *L. amia* with their own tags, removing the original tag as to increase their own total number of fish tagged. This practice is problematic when undertaking stock assessments with tag-recapture models such as Schnabel and Petersen population estimates, which need to know the number of recaptured fish that are re-tagged.

Table 3.2: Total number of *Lichia amia* tagged and recaptured in each region along the South African coast (1984-2006) with corresponding recapture rates.

Province	Region	No. Tagged	No. Recaptured	Recapture Rate (%)
KZN	MP	5	0	0.00
	ZL	67	28	41.79
	GD	275	78	28.36
	SC	144	35	24.31
Eastern Cape	Trans.	533	23	4.32
	Bor.	186	19	10.22
	LEC	3 465	193	5.57
Western Cape	SCp	1 401	57	4.07
	LWC	380	24	6.32
SA coast		**6 456**	**457**	**7.08**

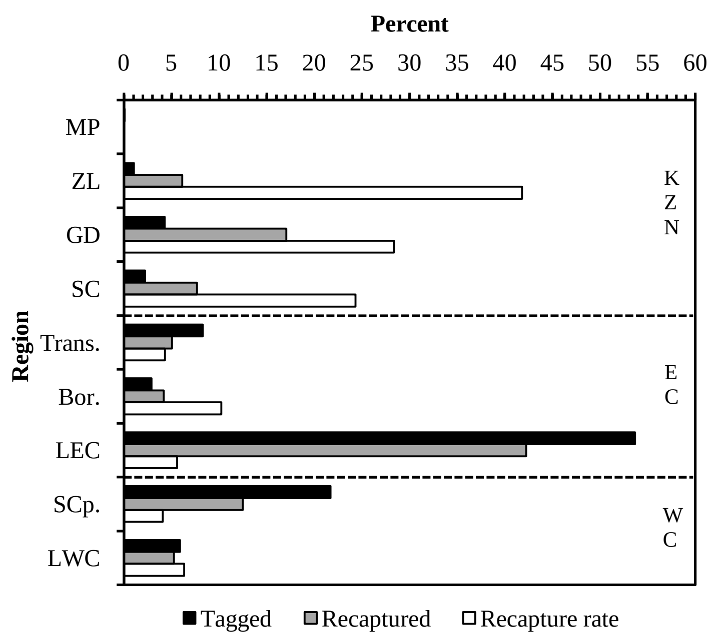


Figure 3.1: Recapture rate and percentage of *Lichia amia* tagged and recaptured in each region along the South African coast 1984-2006.

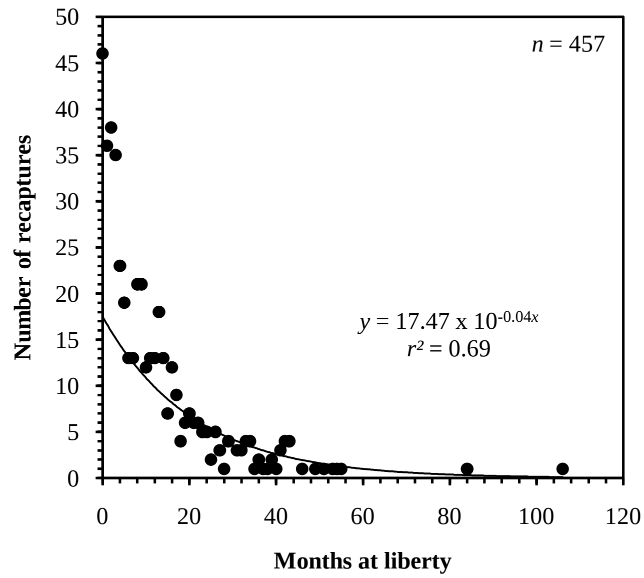


Figure 3.2: Number of recaptures and months at liberty of *Lichia amia* tagged along the South African coast (1984-2006).

In KZN and the Western Cape, the number of *L. amia* tagged remained fairly constant with only slight inter-annual variations (Figure 3.3a). However, in the Eastern Cape, large peaks occurred in the number of *L. amia* tagged in 1991-93 and 2005-06. The number of recaptures in the Eastern Cape followed a similar trend to the number tagged, i.e. peaks in 1991-94 and 2006 (Figure 3.3b). Recaptures in KZN were highly variable each year (especially between 1991 and 2003), with those in the Western Cape remaining reasonably constant throughout the given time period except for a slight peak in 1990, 1994, and 1997, and a sharp decrease in 1996 (Figure 3.3b).

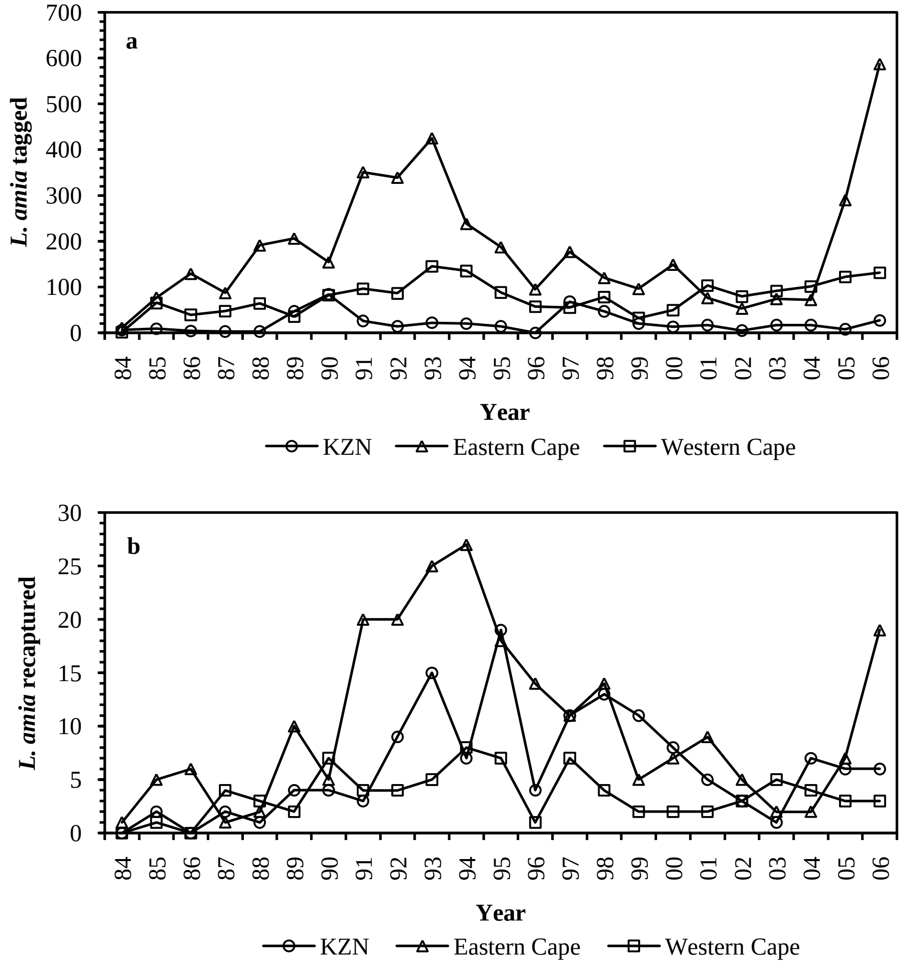


Figure 3.3: Annual variation in the total number of *Lichia amia* tagged (a) and recaptured (b) per province along the South African coast (1984-2006).

Both tagging and recaptures of *L. amia* were highest in the summer months (October-March) in the Eastern and Western Cape (Figure 3.4a and b). During the summer months, few fish were tagged and/or recaptured in KZN. During the winter months (April-September), far more *L. amia* were tagged and recaptured in KZN with the opposite occurring in the Eastern and Western Cape (Figure 3.4a and b).

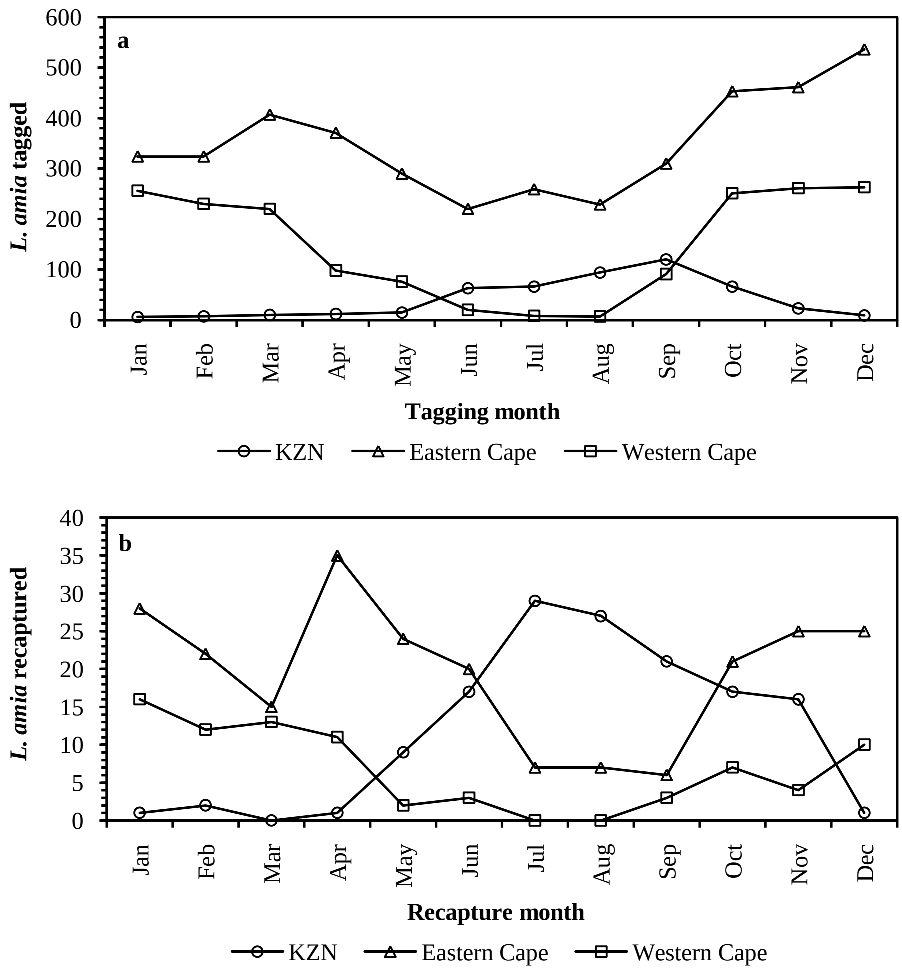


Figure 3.4: Monthly variation in the total number of *Lichia amia* tagged (a) and recaptured (b) per province along the South African coast (1984-2006).

Although 6 456 *L. amia* were tagged, the length information for only 4 429 of these fish could be verified (i.e. type of measurement indicated). Of these, 1 109 fish were tagged and 119 recaptured that were greater than the legal size limit (>587 mm FL), while 3 124 were tagged and 180 recaptured smaller than the size limit (<587 mm FL). Thus, the recapture rate of legal size *L. amia* was much higher than that of undersize fish, i.e. 10.74% and 5.76% respectively.

Of the *L. amia* with verified lengths, 292 were tagged in KZN (average length = 747 mm FL). Very few of these *L. amia* were below the size limit (22%), while 78% were above and a high proportion (46%) of fish were larger than the length at 50% maturity (800 mm FL) (Figure 3.5a). In comparison to KZN, more fish (2 754) of a smaller average size (501 mm FL) were tagged in the Eastern Cape. Of these, the majority (75%) were under the legal size limit (Figure 3.5a). A large number of *L. amia* tagged in the Western Cape also had release lengths which could be verified (n = 1 383). These fish had a similar average length to those in the Eastern Cape (509 mm FL), and the majority were below the size limit (79%). In the Western Cape, the highest proportion (19%) of the *L. amia* tagged were around 550 mm FL (Figure 3.5a).

The length frequency of *L. amia* recaptured in each province was very similar to that of those tagged, especially in the Eastern Cape (Figure 3.5b). In KZN a small number of *L. amia* <587 mm FL were tagged, while no fish this size were recaptured. Similarly, very few *L. amia* recaptured in the Western Cape were below the legal size limit, with the majority between 587 and 800 mm FL (the size limit and length at 50% maturity). With such a small percentage of juvenile *L. amia* caught in KZN, these data highlight the importance of estuaries and protected inshore surf-zones in the Cape as nursery areas for juvenile *L. amia* (Lasiak, 1981; Smale and Kok, 1983; Bennett, 1989a; Bennett, 1989b; Whitfield, 1990).

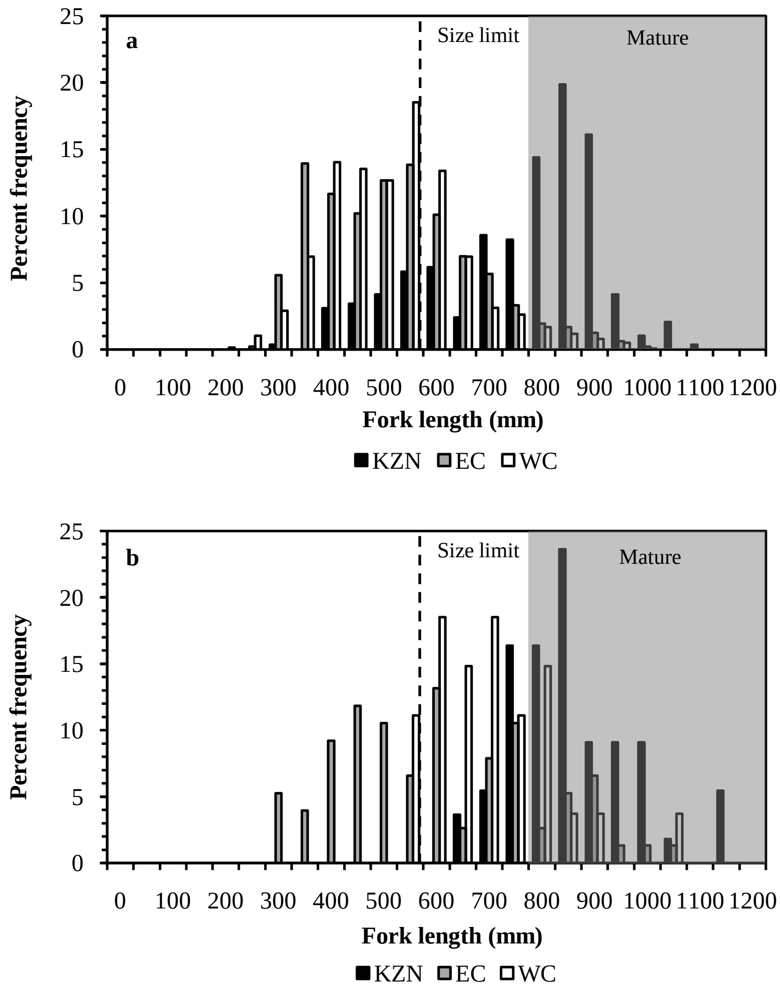


Figure 3.5: Length frequency of *Lichia amia* tagged (a) and recaptured (b) per province along the South African coast (1984-2006).

Movement behaviour

Spatial and temporal movement

When considering all the tag-recapture data, a large proportion of all the recaptured *L. amia* showed northerly movement (39%) while far less showed southerly movement (17%) (Table 3.3). The majority (45%) however, showed no movement as they were tagged and recaptured in the same location (D = 0 km). Of the fish that showed no movement, 192 (94%) were tagged and recaptured in the Eastern and Western Cape. Most of these fish (85%) were at liberty for ≤365 days and these were most likely juvenile fish tagged in estuaries that did not take part in the northerly migration to KZN for winter. The lack of movement by these fish could also have been a result of mouth closure of an estuary, which occurs when there is insufficient rain and/or wave action to maintain the mouth open and fish become trapped in the estuary. Sub-adult and adult fish were also recaptured in the same location as initially released because, similar to juvenile fish, they can also become trapped in estuaries and/or because they returned to the same location after migrating (i.e. because of abundance of prey). In addition, each year anglers target *L. amia* in locations that produce good catches (e.g. Tugela River mouth along the KZN coast, Chapter 2), which may be a site where fish aggregate.

Table 3.3: Summary of movement data for all tagged *Lichia amia* recaptured (1984-2006).

Movement direction	**Displacement in km (*D*)**			**Days at liberty (*dt*)**			**Speed in km/day (*D/dt*)**		
	Mean	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
North (*n* =177)	586.05	1	1670	534.77	8	1660	1.68	0.01	12.28
South (*n* = 76)	218.63	1	1186	346.75	7	2563	1.51	0.01	13.87
Zero (*n* = 204)	-	-	-	176.62	1	3239	-	-	-
Overall mean	**263.34**			**352.71**			**0.90**		

Larger *L. amia* undertook greater movements than smaller *L. amia* (Figure 3.6). An increase in the distance travelled as fish approach the legal minimum size limit (≥587 mm FL) is clear. In addition, *L. amia* >500 mm FL showed high variability in the distance moved compared to smaller fish (indicated by the high standard deviation). Fish in the 950 mm FL size class showed the greatest variability in distance moved, although few fish >950 mm FL were tagged and recaptured (Figure 3.6). *L. amia* <500 mm FL undertook small movements with those in the 350 mm FL size class (*n* = 23) all recaptured in the same location as released and did not undertake any noticeable movement.

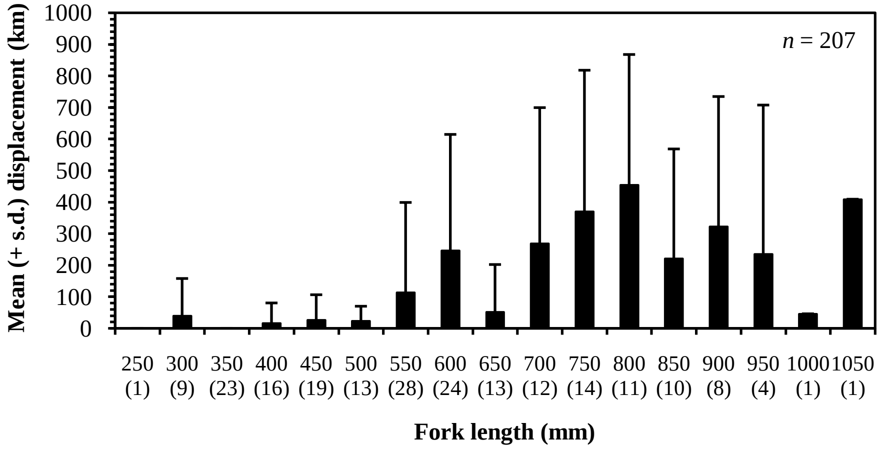


Figure 3.6: Mean displacement (km) and standard deviation by different size classes of recaptured *Lichia amia*. Numbers in parenthesis indicate sample size.

For those tagged and recaptured *L. amia* that undertook northerly and southerly movements, once over the legal size limit (≥587 mm FL) fish are more likely to be recaptured than smaller fish (i.e. lower days at liberty than smaller fish) (Table 3.4).

Table 3.4: Minimum, maximum and mean (with CV's as a proportion) days at liberty (*dt*) for *Lichia amia* tagged (below and above the legal size limit) and recapture after migrating north and south along the South African coast (1984-2006).

L. amia	**Days at liberty**		
size (mm FL)	**Min.**	**Max.**	**Mean (CV)**
<587 (*n* = 81)	20	1660	594 (0.68)
≥587 (*n* = 53)	8	1599	399 (0.91)

When considering only those *L. amia* recaptured ≤365 days after tagging, the majority which had moved north and/or south were close to or above the legal size limit (≥587 mm FL) (Figure 3.7). Conversely, the majority of *L. amia* that were tagged and recaptured in the same locality were immature and below the minimum legal size limit (Figure 3.7).

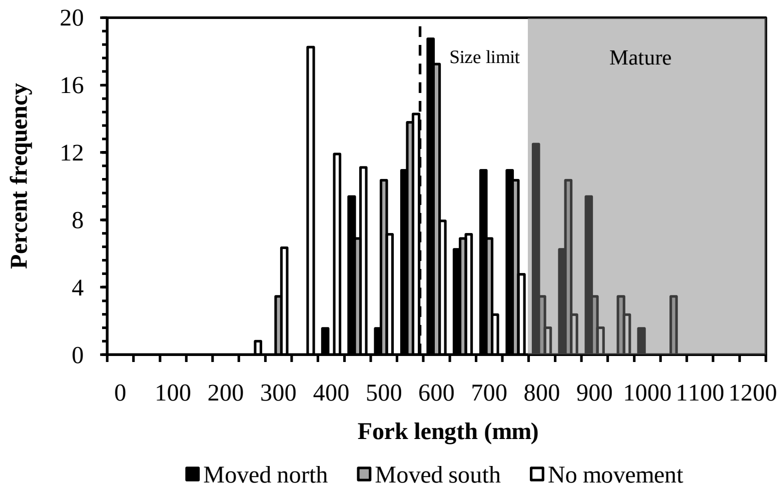


Figure 3.7: Length frequency of *Lichia amia* tagged and recaptured along the South African coast that had undertaken northerly, southerly or no movement, with a time at liberty ≤365 days. Dashed line represents minimum size limit.

Fewer *L. amia* at liberty for ≤365 days had undertaken southerly than northerly movements (Table 3.5). The majority (52%) of the fish that had moved north, undertook large (≥201 km) movements, while 38% undertook small (≤100 km) and only 10% medium (101-200 km) movements (Table 3.5). Whereas, the majority (49%) of those fish that had moved south were recaptured within 100 km of the tagging location, 47% undertook large southward movements and only 5% moved between 101-200 km (Table 3.5).

There was a significant difference in the displacement (≥201 km) of *L. amia* moving north and south in winter and summer months (H_c = 87.663, $\chi^2_{0.05,3}$ = 7.815). The majority (80%) of these fish moved north after being tagged in summer, while the majority of fish moved south (54%) after being tagged in winter.

No significant difference (p>0.05) in the minimum speed (km/day) of migration was detected between fish that had moved ≥201 km northward in Autumn/Winter when compared to fish that moved southward in Spring/Summer (p = 0.363, t (1.72) = 0.36).

Table 3.5: Summary of northerly and southerly movement data for recaptured *Lichia amia* at liberty for ≤365 days (1984-2006).

North (*n* = 79)									
Movement distance (km)	***D* (km)**			***dt* (days)**			***D/dt* (km/day)**		
	Mean	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
≤100 (*n* = 30)	25.63	1	89	135.87	8	363	0.48	0.03	5.75
101-200 (*n* = 8)	150.13	121	192	121.63	29	255	1.98	0.52	4.24
≥201 (*n* = 41)	742.88	257	1 443	227.27	70	361	4.14	0.89	12.28
South (*n* = 44)									
Movement distance (km)	***D* (km)**			***dt* (days)**			***D/dt* (km/day)**		
	Mean	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
≤100 (*n* = 24)	27.21	1	89	135.29	7	365	0.56	0.02	7.50
101-200 (*n* = 6)	159.83	108	198	190.00	62	326	1.22	0.51	3.16
≥201 (*n* = 14)	608.57	217	1 173	158.64	174	208	5.75	0.67	13.87

The short (<100 km) or medium (101-200 km) movements of individual *L. amia* that were at liberty for ≤365 days are shown in Figure 3.8 and 3.9. Although small-scale movements (north and south) were recorded through the constrained 24-month period, a large number of individual *L. amia* began moving northwards with the onset of winter and southwards with the onset of summer (Figure 3.8 and 3.9). However, of the individual *L. amia* that were tagged and moved short or medium distances, the majority were tagged in the Cape and very few in KZN.

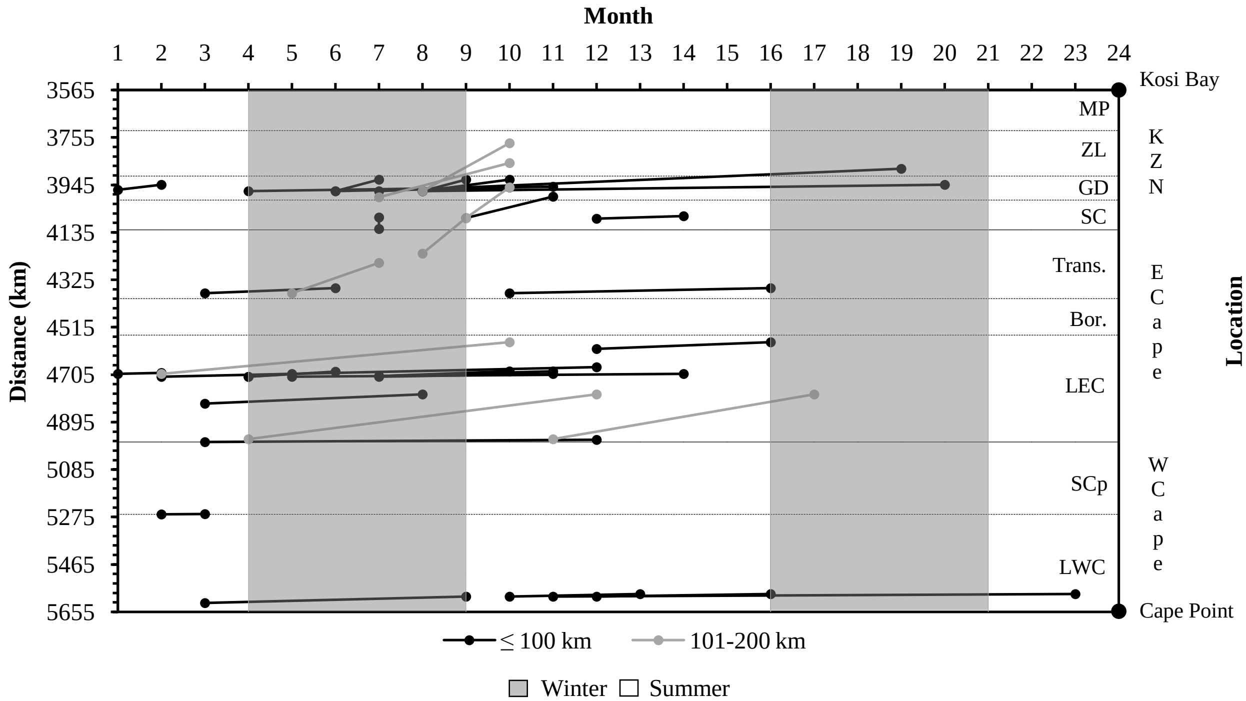


Figure 3.8: Displacement (km) by location and month of tagging and recapture for individual *Lichia amia* moving ≤ 100 km and 101-200 km north from their tagging location.

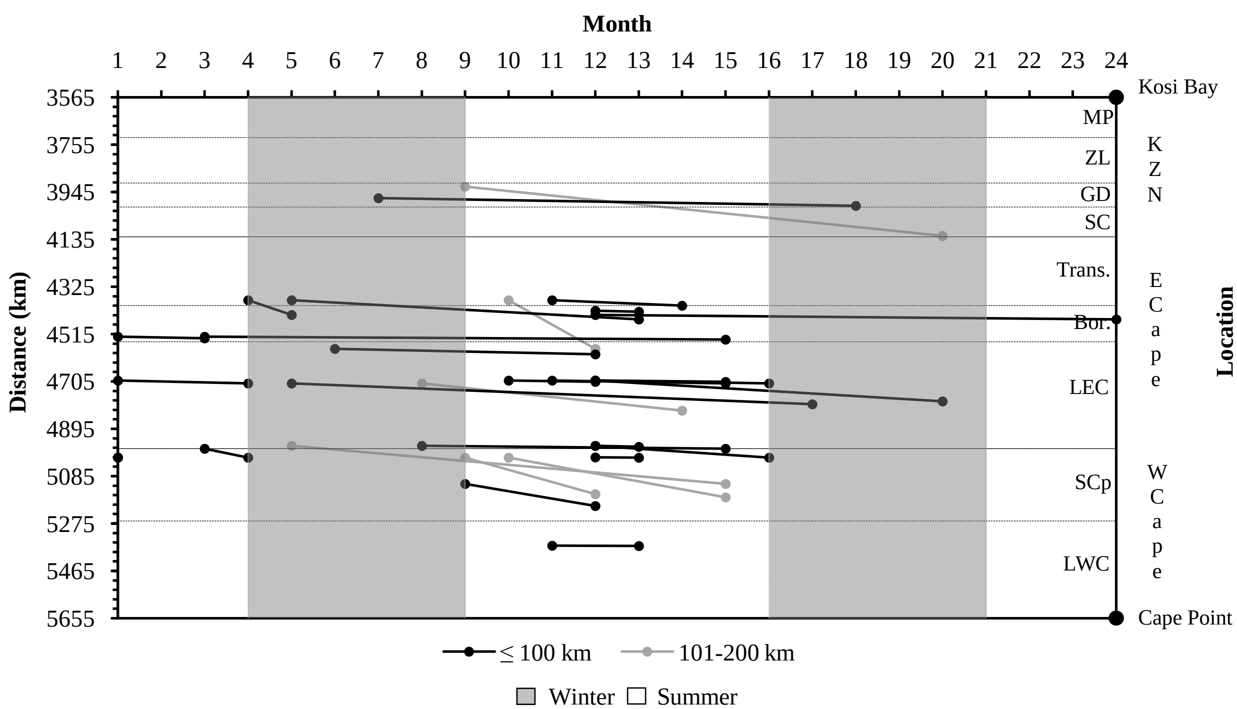


Figure 3.9: Displacement (km) by location and month of tagging and recapture for individual *Lichia amia* moving ≤ 100 km and 101-200 km south from their tagging location.

When considering the large (≥201 km) northerly and southerly movements, the majority of *L. amia* tagged in the Cape during the summer months (January-March) were recaptured in KZN in winter (April-September) of the same year (Figure 3.10). Correspondingly, the majority of *L. amia* undertaking ≥201 km movements southwards were tagged in winter on the lower KZN south coast, and recaptured five months later in the Cape during summer (Figure 3.10). Those *L. amia* were tagged in the Cape later on in the year in summer (October-December) and moved ≥201 km north, were recaptured the following year in KZN during winter (April-September). The large northerly and southerly movements of these individual *L. amia* illustrate the seasonal migration patterns of sub-adult and adult *L. amia*.

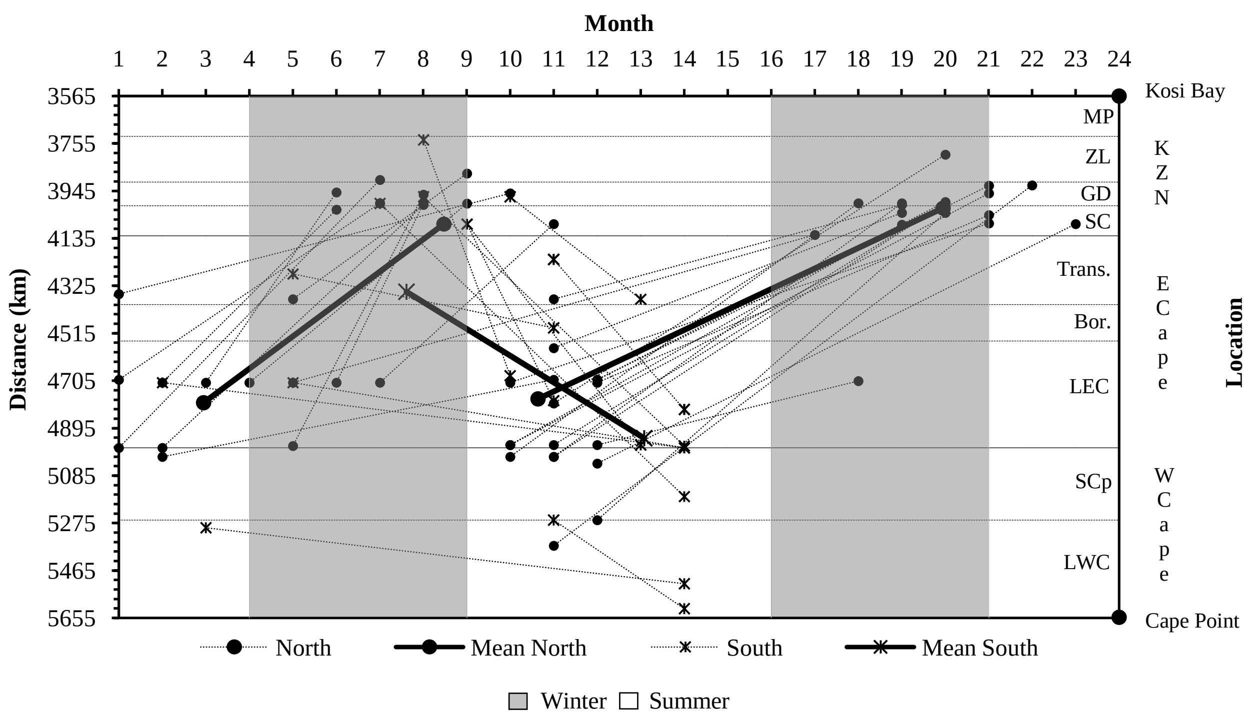


Figure 3.10: Displacement (km) by location and month of tagging and recapture for individual *Lichia amia* moving ≥201 km north and south from their tagging location. Bold lines indicate means.

Movement model

Unfortunately, when modelling the movement of *L. amia* it was not possible to estimate fishing effort directed at *L. amia* along the Cape coast ($E_{c,t}$) each year from 1984-2006 (see Eq. 3.3). $E_{c,t}$ was estimated by combining raw data from a roving creel census conducted in the former Transkei during 1997 (Mann *et al*., 2003) and from another census conducted along the rest of the Eastern Cape coast (Kei Mouth to Stil Bay) during 1994-96 (Brouwer, 1997). $E_{c,t}$ thus was assumed to be constant and was calculated as 0.002 angler/km. This was considerably lower than the average fishing effort directed at *L. amia* in KZN during the period 1984-2006, which was calculated as 0.012 angler/km based on the EKZNW shore patrol data (Chapter 2). The average "killing rate" (1984-2006) was also higher in KZN (90% of recaptured *L. amia* were killed) than in the Cape (80% killed).

The probability of movement ($p_{n,c}$ and $p_{c,n}$) was estimated with relatively narrow confidence limits, and increased with increasing rates of M as these were confounded within the model. The catchability coefficients (q_n and q_c) were not affected by increasing rates of M, but were the most poorly estimated parameters with wider confidence limits than the those estimated for $p_{n,c}$ and $p_{c,n}$. Surprisingly, for all values of M, the model predicted a higher probability of movement from KZN to the Cape ($p_{n,c}$) than from the Cape to KZN ($p_{c,n}$). This was in contrast to that shown in Table 3.3 and Figures 3.8-3.10 (i.e. more *L. amia* undertook northerly migrations from the Cape to KZN). The average fishing mortality was higher for *L. amia* in KZN (0.05 year^{-1}) than in the Cape (0.03 year^{-1}). This was to be expected with higher fishing effort directed at *L. amia* in KZN than in the Cape. Estimated fishing mortality rates for *L. amia* in KZN per year (1984-2006) for M = 0.4 year^{-1} (van der Elst *et al*., 1993), showed a slight decreasing trend mainly because of decreasing fishing effort directed at *L. amia* in KZN over the given time period (Figure 3.11).

Table 3.6: Movement model parameter estimates for *Lichia amia* at different *M* values from all tag-recapture data (1984-2006) with 95% confidence limits.

	***M* = 0.3 year^{-1}**		***M* = 0.4 year^{-1}**		***M* = 0.5 year^{-1}**	
Parameter	**Estimate**	**95% CL**	**Estimate**	**95% CL**	**Estimate**	**95%CL**
$p_{n,c}$	1.32	1.24 - 1.38	1.46	1.41 - 1.50	1.61	1.51 - 1.69
$p_{c,n}$	0.79	0.60 - 0.93	0.88	0.66 - 1.03	0.97	0.73 - 1.14
q_n	5.04	3.54 - 7.18	5.04	3.54 - 7.18	5.04	3.54 - 7.18
q_c	17.86	13.75 - 23.39	17.86	13.75 - 23.39	17.86	13.7 - 23.39

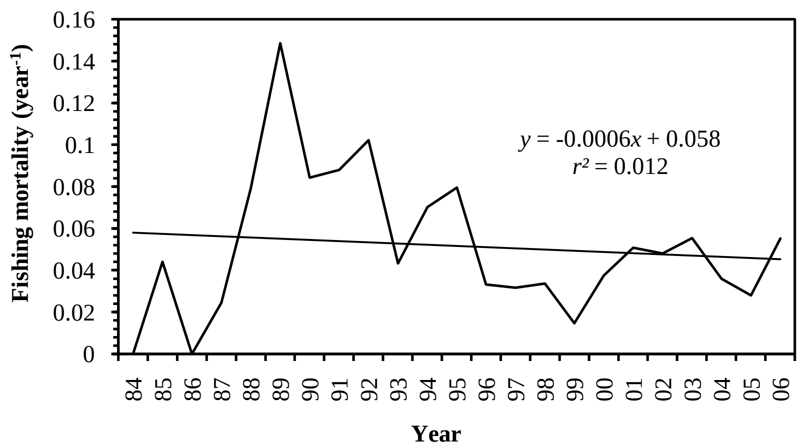
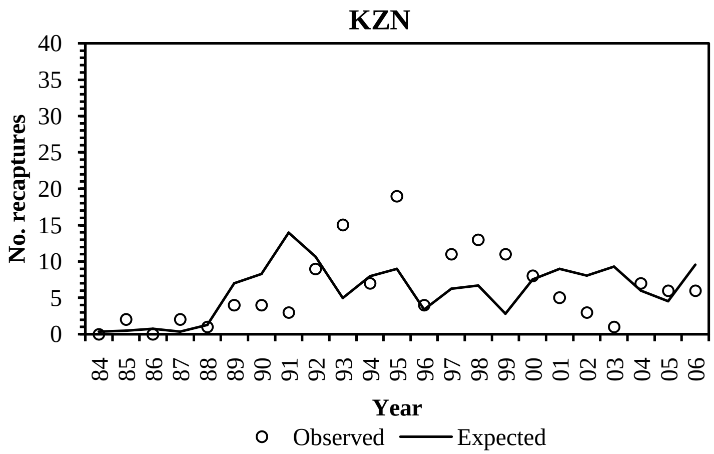


Figure 3.11: Estimated fishing mortality rates (year^{-1}) for *Lichia amia* in KwaZulu-Natal (1984-2006). Parameter estimates are shown in Table 3.6 for M = 0.4 year^{-1}.

The observed and expected (model-derived) recaptures of tagged *L. amia* along the South African coast (1984-2006) showed good correlation and resulted in relatively low deviance values (Figure 3.12 and Table 3.7). Lower values of deviance indicate better agreement between the observed and expected recaptures of tagged *L. amia*. With far more data for the Cape, the model fitted the Cape data better than the KZN data and deviance was thus lower between the observed and expected recaptures in the Cape than those in KZN (Figure 3.12 and Table 3.7).

In an attempt to improve the fit to the data, only those *L. amia* that were tagged ≥587 mm FL were used and the model was re-run. *L. amia* ≥587 mm FL are expected to undertake large migrations and not be confined to estuaries (Figure 3.6). The values of $E_{n,t}$ and $E_{c,t}$ used when initially running the model with all the tag-recapture data were left unchanged when re-running the model, as these estimates could not be made size-specific. *M* was set at 0.4 year^{-1} (van der Elst *et al*., 1993).

The average killing rate of *L. amia* that were tagged ≥587 mm FL was slightly lower for both KZN (80%) and the Cape (70%) than when using all the data. The estimated fishing mortality in KZN decreased from 1992-2006 (Figure 3.13), the average of which (0.19 year^{-1}) was once again higher than that estimated for the Cape (0.03 year^{-1}). In years where no *L. amia* smaller than the minimum size limit were caught or recaptured, *F* could not be estimated. Since the killing rate was estimated as zero, in these years, these data were omitted when plotting *F* against time (Figure 3. 14).



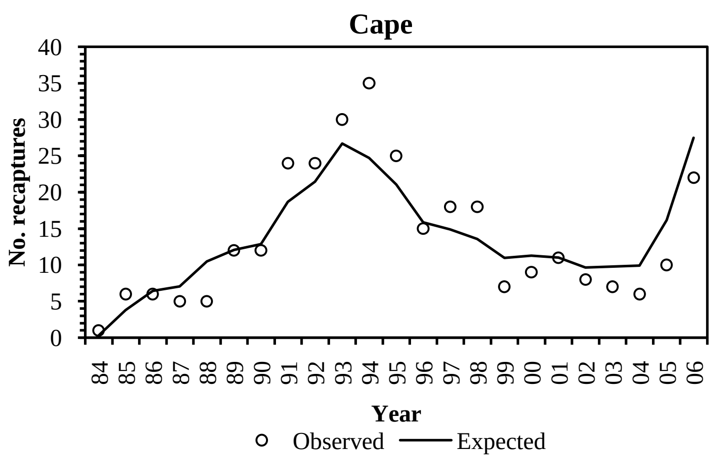


Figure 3.12: Observed and expected recaptures of *Lichia amia* from all tag-recapture data in KwaZulu-Natal and the Cape (1984-2006).

Table 3.7: Observed and expected recaptures, with calculated deviance, of *Lichia amia* in KwaZulu-Natal and the Cape (1984-2006).

Year	KZN			Cape		
	Obs.	Exp.	Dev.	Obs.	Exp.	Dev.
84	0	0.35	-0.74	1	0.30	1.65
85	2	0.46	3.79	6	3.78	3.67
86	0	0.75	-0.43	6	6.42	1.55
87	2	0.35	4.84	5	7.04	0.48
88	1	1.25	0.11	5	10.46	5.01
89	4	6.99	4.83	12	12.05	0.24
90	4	8.26	3.12	12	12.84	4.29
91	3	13.96	16.25	24	18.69	5.70
92	9	10.63	3.12	24	21.47	3.27
93	15	4.95	17.29	30	26.67	4.95
94	7	7.97	4.04	35	24.72	8.76
95	19	8.99	13.51	25	21.04	1.11
96	4	3.38	1.26	15	15.84	4.63
97	11	6.25	4.43	18	14.87	5.50
98	13	6.69	7.97	18	13.56	4.53
99	11	2.81	16.71	7	10.95	5.76
00	8	7.54	2.30	9	11.27	1.58
01	5	9.00	1.55	11	11.01	0.05
02	3	8.07	3.53	8	9.66	3.12
03	1	9.28	11.29	7	9.76	4.05
04	7	6.00	0.32	6	9.93	5.58
05	6	4.55	2.40	10	16.15	3.11
06	6	9.57	3.67	22	27.48	4.16

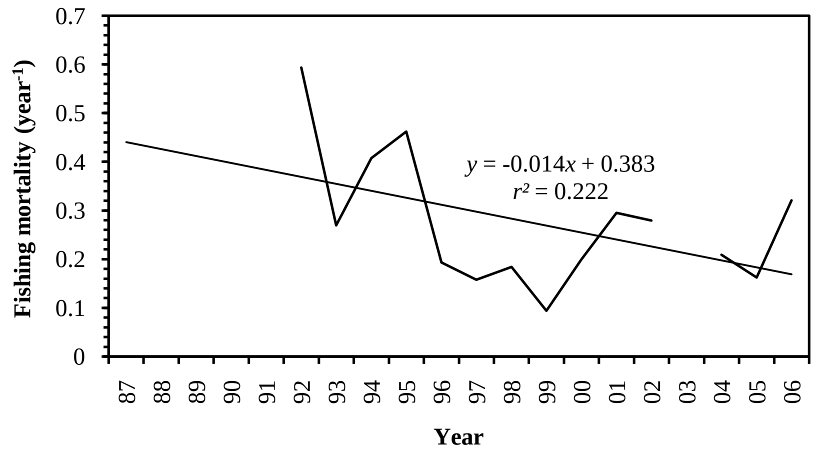


Figure 3.13: Estimated fishing mortality rates (year^{-1}) for *Lichia amia* that were tagged at ≥587 mm FL in KwaZulu-Natal (1987-2006). Parameter estimates are shown in Table 3.8 for M = 0.4 year^{-1}.

The probability of movement from the Cape to KZN ($p_{c,n}$) was slightly higher than that from KZN to the Cape ($p_{n,c}$), while the catchability coefficient was higher in KZN than in the Cape (Table 3.8). The probability of movement from KZN to the Cape ($p_{n,c}$) and the Cape to KZN ($p_{c,n}$) was smaller than that estimated when using all the tag-recapture data for M = 0.4 year^{-1} (Table 3.6). The catchability coefficients (q_n and q_c) were much higher for the *L. amia* tagged ≥587 mm FL, especially in KZN (q_n). The wider range of confidence limits suggests that the parameters were not as well estimated as in the model when using all the data (Table 3.6). However, when considering the fit of the expected to the observed recaptures (Figure 3.14 and Table 3.9), the expected recaptures were a lot closer to the observed values resulting in lower deviance between the two than when running the model with all the data.

Table 3.8: Movement model parameter estimates for *Lichia amia* tagged at ≥587 mm FL (1987-2006) for M = 0.4 year^{-1} with 95% confidence limits.

Parameter	Estimate	95% CL
$p_{n,c}$	0.72	0.45 - 0.95
$p_{c,n}$	0.79	0.33 - 1.11
q_n	29.27	19.51 - 41.25
q_c	25.40	15.17 - 40.31

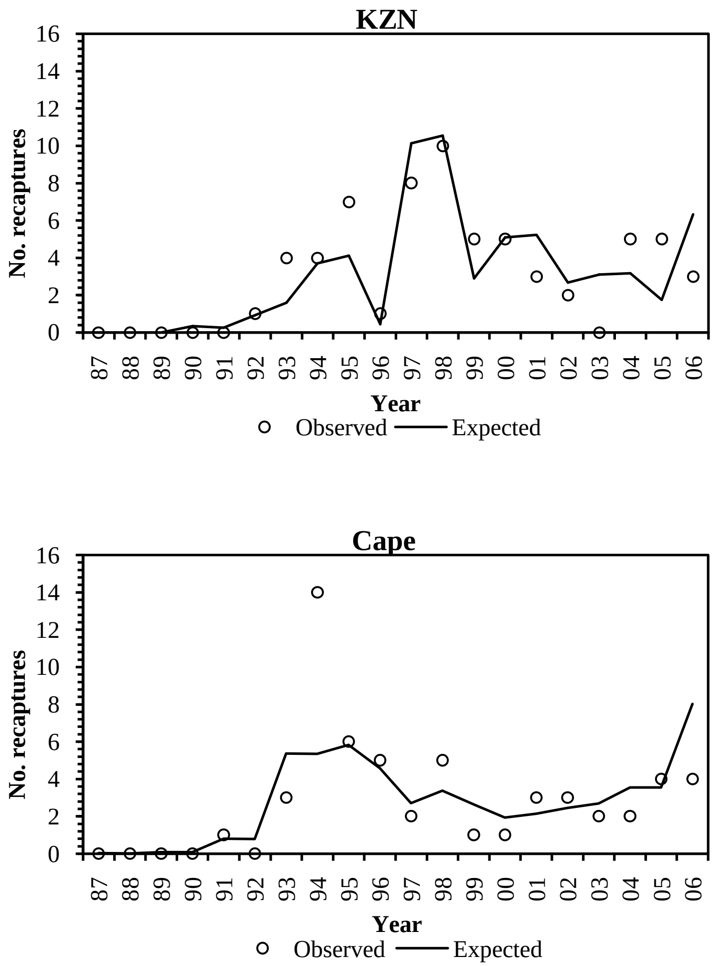


Figure 3.14: Observed and expected recaptures of *Lichia amia* tagged at ≥587 mm FL in KwaZulu-Natal and the Cape (1987-2006).

Table 3.9: Observed and expected recaptures, with calculated deviance, of *Lichia amia* tagged at ≥ 587 mm FL in KwaZulu-Natal and the Cape (1987-2006).

Year	KZN			Cape		
	Obs.	**Exp.**	**Dev.**	**Obs.**	**Exp.**	**Dev.**
87	0	0.00	0.00	0	0.04	-0.31
88	0	0.00	0.00	0	0.02	-0.19
89	0	0.00	0.00	0	0.08	-0.58
90	0	0.34	-0.73	0	0.08	-0.56
91	0	0.26	-0.70	1	0.80	0.04
92	1	0.93	0.01	0	0.78	-1.95
93	4	1.59	4.11	3	5.36	1.50
94	4	3.70	2.00	14	5.35	7.02
95	7	4.12	2.54	6	5.83	0.00
96	1	0.45	0.88	5	4.57	0.04
97	8	10.14	0.89	2	2.71	0.23
98	10	10.55	2.58	5	3.38	0.60
99	5	2.89	3.71	1	2.64	1.85
00	5	5.10	0.32	1	1.93	0.68
01	3	5.23	1.41	3	2.14	0.28
02	2	2.67	1.32	3	2.46	0.10
03	0	3.09	3.41	2	2.69	0.22
04	5	3.17	1.77	2	3.55	0.97
05	5	1.74	5.97	4	3.55	0.05
06	3	6.33	2.73	4	8.02	3.12

3.4 Discussion

L. amia are a highly sought-after gamefish and have proved to be a popular fish to tag. This species has a relatively high tag and recapture rate with 6 456 fish tagged and 457 (7.08%) recaptured from 1984-2006. With such a high recapture rate, the majority of *L. amia* were recaptured within a year of release. On a provincial and regional scale, the majority of *L. amia* were tagged and recaptured in the Eastern and Western Cape, especially in the lower Eastern Cape (LEC) and Southern Cape (SCp) regions (Table 3.2). The majority of these fish were juvenile *L. amia* smaller than the legal minimum size limit (<587 mm FL) and were caught in estuaries and near river mouths. In contrast, the majority of *L. amia* tagged and recaptured in KZN were caught in the surf-zone and were ≥587 mm FL. Far fewer *L. amia* were tagged and recaptured in KZN, with the exception of in the Greater Durban (GD) region that had the second highest number of recaptures after the lower Eastern Cape region. Recapture rates were higher in KZN than in the Cape (Table 3.2).

The annual trends in the number of *L. amia* tagged and recaptured in KZN and the Western Cape from 1984-2006 were reasonably consistent. In contrast, the number of *L. amia* tagged and recaptured in the Eastern Cape varied more than in the other two provinces. Seasonal differences in the number of *L. amia* tagged and recaptured in the Cape and KZN clearly indicate seasonal abundance in both areas. In KZN the majority of *L. amia* were tagged and recaptured in winter/spring months (May-November) with the inverse occurring in the Western and Eastern Cape. More *L. amia* were tagged throughout the year in the Eastern Cape than in the Western Cape and KZN.

Differential patterns and rates of tagging and recapture, as seen for *L. amia* along the South African coast, are related to fishing effort, seasonal abundance (Gillanders *et al*., 2001), life-history characteristics, tag-shedding, tag-associated mortalities (Kohler and Turner, 2001) and environmental factors. According to Sheridan and Castro Melendez (1990) spatial and temporal variations in fishing effort will influence patterns of recapture of tagged organisms, with fewer releases and recaptures in regions along the coast with lower fishing effort. The high recapture rate along the KZN coast can thus be attributed to the high effort directed at *L. amia* in this province, especially in the Greater Durban region. Nevertheless, when considering the spatial variations in fishing effort along the South African coast, it does not fully reflect the pattern of tagging and recapture seen for *L. amia* in the Cape.

Although fishing effort directed at *L. amia* in the Cape was lower than in KZN, far more *L. amia* were tagged and recaptured than in KZN (Table 3.2). Thus, fishing effort directed at *L. amia* in the Cape must be higher than that found in this study. Alternatively, this may be a reflection of the state of the adult population in comparison to juveniles, i.e. a smaller adult population would result in higher recaptures and a shorter time at liberty as shown in Table 3.4. By identifying individual taggers in the ORI/WWF-SA Tagging Project, who focus on tagging *L. amia*, greater clarity was obtained in explaining the pattern of tagging and recapture along the South African coast. Several taggers identified in the project (e.g. B. Sparg, C. Lillford, G. Pope, C. Schoultz, B. Carr and A. Kruger) target juvenile *L. amia* almost exclusively in Eastern and Southern Cape estuaries (e.g. in the Gouritz, Goukamma and Knysna estuaries). These individuals target juvenile *L. amia*, and in so doing increase the number of fish tagged and recaptured in these regions (E. Bullen, ORI, *pers. comm.*). This in turn explains the dominance of juveniles in the length frequency of tagged and recaptured *L. amia* in the Cape (Figure 3.5). Consequently, years with exceptionally high numbers of *L. amia* tagged and recaptured in the Eastern Cape could coincide with the introduction of such a avid tagger to the tagging project.

However, increased fishing effort is not the only variable that can affect tag-recapture trends. The success of the taggers targeting juvenile *L. amia* in Cape estuaries will vary depending on environmental factors. The variable recruitment of juveniles into the Cape estuaries, undoubtedly has an impact on the catches in subsequent years. This recruitment is dependent on factors such as rainfall and wave action, both of which contribute to opening mouths of and deepening channels into estuaries (Marais, 1982; Smale and Kok, 1983; Bennett *et al*., 1985; Whitfield and Kok, 1992). The success rate of reproduction by *L. amia* is dependent on the number of surviving adult fish, and juvenile survival is in turn, dependent on the abundance of suitable habitat and prey.

With this large potential variation in annual recruitment, the consistency of the tag-recapture rates over the last two decades warrants some explanation. Although trends in *CPUE* and catches of *L. amia* decreased over the same period (Chapter 2), the popularity of *L. amia* as a game fish and increasing effort directed at *L. amia* by taggers each year (with the annual increase in the number of taggers in the project) has ensured a relatively consistent tagging and recapture of *L. amia*.

The life-history characteristics of *L. amia* explain the seasonal abundance in the different provinces along the South African coast. Trends in the number of *L. amia* tagged and recaptured per province result from the seasonal migration of sub-adult and adult *L. amia*, and the resident behaviour of juveniles (Day *et al*., 1981; van der Elst, 1988). Sub-adult and adult *L. amia* (>500 mm FL) were shown to migrate from the Cape to KZN in early winter months (April-June), where they are available to anglers in KZN up until October-November, after which a return migration back to the Cape occurs. These migrating *L. amia* were shown to be capable of undertaking large migrations in a year (max 1 443 km) at relatively high speed (max 13.38 km/day). No difference in swimming speed was detected between northerly and southerly migrations (4.14 km/day north and 5.75 km/day south). The seasonal migration often in association with prey species *Sardinops sagax* (sardines) and *Pomatomus saltatrix* (elf/shad). In fact, Govender (1995a) showed *P. saltatrix* to migrate at a very similar speed to that found for *L. amia* in this study. While tagging of *L. amia* still occurred in KZN during November, other fish had already been recaptured in the Cape in October after having been initially tagged in early winter in KZN (April-June). This indicates migration is asynchronous, as proposed by Smale (1983). The relatively high number of tagged and recaptured fish in the Eastern Cape during winter (April-September) was a result of taggers targeting resident juvenile *L. amia* (in estuaries) that had not joined the migrating adult population.

Seasonal migration appears to be largely spawning related with mature *L. amia* (>800 mm FL) making up a large proportion (46%) of fish that migrated to KZN. Spawning occurs off the Tugela region of the KZN coast from September through to November (van der Elst *et al*., 1993). However, non-spawning related migrations of immature *L. amia* between 500 and 800 mm FL occurred with 54% of migrating fish in this size class. These migrations may be related to an increase in optimum habitat availability with decreasing water temperatures in KZN during winter, and/or a feeding related migration (following *P. saltatrix* and *S. sagax*) (Harden Jones, 1968). It is also possible that van der Elst *et al*. (1993) over-estimated the size at maturity of *L. amia*, and many of the fish between 500-800 mm FL may well have been mature. Potts *et al*. (2008) found that *L. amia* in southern Angola mature at 623 mm FL, but determination of size at maturity was beyond the scope of this study.

Larger *L. amia* (≥587 mm FL) were found to have shorter times at liberty than juvenile fish (Table 3.4). The seasonal migration of these larger *L. amia* to KZN from the Cape is one of the contributing factors for the shorter time at liberty, as fishing effort directed at *L. amia* is higher in

KZN than in the Cape, and thus a higher recapture and fishing mortality rate would be expected. Similarly, Gillanders *et al*. (2001) found differences in recovery rate with size, i.e. recapture of larger fish was more likely. Gillanders *et al*. (2001) attributed this to minimum legal size limits (as fish retained illegally are often not reported), selectivity of fishing gear and different rates of tag-associated mortality. The difference in recovery rates with size in this study can be attributed to similar reasons. Larger stronger fish, which are easier to tag, swim off more strongly and are less prone to predation once released, thus reducing tag-associated mortality and increasing the chances of recapture after a short time at liberty. Larger fish would also out-compete smaller fish for available prey, further increasing the chance of recapture. The decreasing days at liberty could (Table 3.4) also be an indication of a smaller overall population of mature *L. amia* (as mentioned above). Low abundance of mature fish would result in the high recapture rates (10.73%) with short periods at liberty, as high proportions of tagged fish in the whole population would increase the chances of fish recapture. In a relatively pristine *L. amia* population, such as that off southern Angola (Potts *et al*., 2008), the recapture rate was approximately 5% (W. Potts, Department of Ichthyology and Fisheries Science, Rhodes University, *pers. comm.*). Smaller *L. amia* also have higher rates of natural mortality and tag-associated mortality, which would decrease the recapture rate of smaller fish (as discussed below).

When attempting to quantify the movement behaviour of *L. amia* by means of Hilborn's (1990) general movement model, the expected results were not obtained. The model-predicted probability of movement from KZN to the Cape ($p_{n,c}$) was much higher than from the Cape to KZN ($p_{c,n}$). However, there was a high tag to low recapture ratio in the Cape in comparison to KZN (Table 3.2), indicating that far more tagged *L. amia* moved north from the Cape to KZN than from KZN to the Cape, as seen in Table 3.3 and Figures 3.9-3.11. Running the movement model with all the tag-recapture data unfortunately meant the data were size-biased because of the overwhelming amount of data for juveniles tagged in the Cape (Figure 3.5). The model thus fitted the Cape data better than the KZN data and unrealistic parameter estimates were obtained (in particular $p_{n,c}$ and $p_{c,n}$). The parameter estimates were further biased without incorporating accurate estimates for tag-shedding, tag-associated mortality and non-reporting of tags (Sibert, 1984; Gillanders *et al*., 2001; Shirakihara and Kitada, 2004; McDermott *et al*., 2005), which vary over space and time as a fishery changes (Trumble *et al*., 1990) and between anglers (Hearn *et al*., 1991; Govender and Bullen, 1999; Gillanders *et al*, 2001). As proposed in Hilborn's (1990) study on fish movement patterns, the probability of movement of *L. amia* was shown to be confounded with *M* (Table 3.6) and thus also with tag-shedding and tag-associated mortality. Therefore, varying rates of either tag-shedding and/or tag-associated mortality (which are summed with M in Eq. 3.1) would result in different estimates of $p_{n,c}$ and $p_{c,n}$.

In the Cape, the majority of *L. amia* tagged were juvenile fish, while those tagged in KZN were sub-adult and adult fish. The smaller juvenile fish tagged in the Cape would have higher M values than the larger sub-adult and adult fish tagged in KZN (Ricker, 1969; Wang and Liu, 2006). These juveniles are also more susceptible to tag-associated mortality, with recent work on mortality rates of released fish suggesting that relatively high proportions of released fish do not survive (Bartholomew and Bohnsack, 2005). High natural mortality and tag-associated mortality of juveniles in the Cape could have contributed to the low recapture rate in the Cape in comparison to in KZN. Without incorporating different values of natural mortality for the different areas in the model, and with the probability of movement confounded with M, a higher M in the Cape would have thus resulted in a higher $p_{c,n}$ estimate than obtained.

The catchability coefficients estimated by the model (q_n *and* q_c) were high, as low fishing effort directed at *L. amia* produced relatively large catches. However, limited effort data meant that the effort parameter ($E_{c,t}$) was fixed for the Cape, and thus the effort data were inadequate for quantifying movement rates of *L. amia* and q_c would be meaningless (Xiao, 1996; Aires-da-Silva *et al*., 2005). The low fishing effort directed at *L. amia* in the Cape and KZN (although higher in KZN) further resulted in exceptionally low values of fishing mortality when running the model with all the tag-recapture data. Beverton and Holt (1957) point out that without estimates of the tag-shedding rate, tag-associated mortality rate and non-reporting, F would be underestimated, because these factors generally contribute to a reduced recapture rate. Consequently, the estimated values of F (KZN = 0.09 year^{-1} and Cape = 0.03 year^{-1}) obtained in this study were unrealistic as they indicate an almost un-fished *L. amia* fishery along the South African coast. Potts *et al*. (2008) estimated fishing mortality at 0.03 year^{-1} for *L. amia* in southern Angola, which is largely un-fished and has a relatively pristine population.

Since small fish (<587 mm FL) were shown to be predominantly resident, the model was re-run using fish ≥587 mm FL. This effectively removed the bias resulting from the dominance of small fish tagged in the Cape. The legal size limit for *L. amia* is 587 mm FL and fish this size and above undertake large migrations (Figure 3.6). This effectively "down-weighted" the Cape data by excluding the large number of juveniles tagged in the Cape. As with the entire data set, considerably more *L. amia* ≥587 mm FL were tagged in the Cape than in KZN (four times as many) and the model once again provided a better fit to the Cape data than the KZN data (Table 3.9). However, in contrast with that found when running the model with all the tag-recapture data, the model indicated there was a higher probability of fish moving from the Cape to KZN when using only the *L. amia* that were tagged ≥587 mm FL (Table 3.8). This would be expected based on the high tag to low recapture ratio for the Cape in comparison to KZN (Table 3.2), and the much higher number of tagged *L. amia* that moved north from the Cape to KZN than south from KZN to the Cape (Table 3.3). Although mortality estimates were again unrealistically low (0.03 $year^{-1}$ in the Cape and 0.19 $year^{-1}$ in KZN), using only *L. amia* that were tagged ≥587 mm FL resulted in a better overall fit and the estimates are probably a better reflection of the actual state of the fishery. Nevertheless, parameter estimates would still have been biased without reliable estimates for tag-shedding, tag-associated mortality and non-reporting of tags.

Although tag-shedding and tag-associated mortality do occur, negligible tag-shedding has been observed in the field, with only one *L. amia* out of 90 recaptured off the Angolan coast having had a tag scar (W. Potts, Department of Ichthyology and Fisheries Sciences Rhodes University, *pers. comm.*). Although this is only anecdotal information, one would expect tag-shedding and associated mortality to be relatively low for *L. amia*. Captive tagging with dart tags was shown to have no affect on a similar size Carangid species (*Caranx melampygus*), i.e. all behaved normally, none died and there was no tag-shedding over an extended observation period (Holland *et al*., 1996). In addition, tags do not appear to affect the growth of *L. amia* (Chapter 4). McFarlane *et al*. (1990) considered tag-shedding and tag-associated mortality the most critical issue when evaluating results from tagging experiments, and determining rates of each are necessary to obtain unbiased estimates of migration rates (Shirakihara and Kitada, 2004). Nonetheless, they are difficult to calculate (Hearn *et al*., 1991), as they are confounded with fishing mortality, natural mortality and movement (Hilborn, 1990). Estimates can be obtained from experimental work with fish kept in captivity and/or double-tagging experiments. However, the ORI/WWF-SA Tagging Project is a cooperative tagging project, and as a result, tag-shedding and tag-associated mortality rates vary per tagger with experienced taggers having lower tag-shedding and tag-associated mortality rates (Hearn *et al*., 1991; Govender and Bullen, 1999). Thus, it would be difficult to produce reliable estimates of tag-shedding and tag-associated mortality by means of double tagging unless done under controlled conditions. Furthermore, whether tag-shedding and associated mortality observed in captivity reflects actual field conditions cannot be determined (Gillanders *et al*., 2001). The current methodology of the tagging project therefore restricts methods for estimating values for tag-shedding and associated mortality.

Limitations in the data because of the unequal distribution of tagging effort along the South African coast and the lack of quantified information on variables that affect recapture rates, limit the usefulness of the tag-recapture data obtained from the ORI/WWF-SA Tagging Project. The unrealistic parameter estimates obtained from the movement model in this study are not surprising as, according to Gillanders *et al*. (2001), cooperative tagging projects such as the ORI/WWF-SA Tagging Project are unlikely to provide useful information for estimating important life-history parameters, such as mortality. According to Hilborn (1990) and Xiao (1996), good experimental design needs tagging and release to be done over as wide an area as possible and requires fishing effort data to be available by time for the same area. Thus, in order for the information content of the data from the project to be improved and be useful for more quantitative analyses, tag supply could be limited to different areas along the South African coast to avoid the unequal distribution of tagging effort (Kohler and Turner, 2001). If possible tagging cards should include some kind of information on effort, e.g. time fished, species targeted and even gear type used. Furthermore, in the future, more emphasis should be put on encouraging the reporting of tags, e.g. through better communication with anglers and clubs.

Although requiring huge resources, future research on population dynamics, mortality and migration rates of *L. amia* should be based on a combination of tag-recapture data collected from a dedicated scientific tagging project and the existing cooperative tagging project. A dedicated scientific tagging project would provide more realistic, accurate results and will offer the possibility of better prediction of life-history parameters, but on its own cannot provide the geographical range and numbers of fish a cooperative project can (Gillanders *et al*., 2001). A dedicated tagging project would need to focus on factors such as non-reporting of tags, tag-shedding and tag-associated mortality together with spatial and temporal distribution of effort, and the abundance and distribution of *L. amia* along the South African coast (Gillanders *et al*., 2001). A framework, such as that proposed by Xiao (1996), when designing such a project should be considered as it can be used to evaluate a set of experimental designs for a dedicated tagging project and provide a basis for collecting sufficient data to estimate rates of movement accurately. Telemetry experiments could also be explored for more accurate estimates of movement, mortality and tag-shedding.

These results have provided evidence for an ontogenetic shift in the movement behaviour of *L. amia*. Based on this, management options could be explored on a provincial basis. The heavy targeting of juveniles in the Cape has been highlighted in this study. Appropriate management should ensure these juveniles join the adult spawning population by ensuring adequate protection in their estuarine nursery areas. Although theoretically the minimum size limit should achieve this, it is apparent that estuarine degradation has led to reduced habitat availability for juvenile *L. amia* (Whitfield, 1997; Lamberth and Turpie, 2003). What is also of concern is that although juveniles are targeted with the intention of tagging and release, Bartholomew and Bohnsack (2005) have suggested relatively high proportions of released fish do not survive. For these reasons, greater emphasis should be placed on habitat protection and the development of estuarine protected areas (EPAs) in the Eastern and Western Cape.

In addition to more juveniles tagged in the Cape, a large number of sub-adult and adult *L. amia* (≥587 mm FL) were also tagged in the Cape (four times as many as in KZN). These fish migrate up to KZN, where there was a high number of recaptures and considerably fewer fish tagged than in the Cape. This, as well as the very short time at liberty (Table 3.4) and lower probability of movement out of KZN for these larger fish (Table 3.8) serves as an indication of the high catchability of *L. amia* and the high fishing effort directed at this species while in KZN waters. These larger fish are available to anglers in KZN waters for seven months of the year, during which time mature fish spawn from September-November. Management attention should thus be focused on those months during which spawning *L. amia* are present in KZN and are exposed to high fishing effort. Management considerations incorporating the protection of juvenile *L. amia* in Cape estuaries and larger fish in KZN waters are explored in Chapter 6.

CHAPTER 4
Age and Growth

4.1 Introduction

Studying the age of fish is an important step in establishing a number of important life history parameters such as growth rate, mortality, longevity and age at maturity (Mann, 1992). The knowledge of age of a fish population is one of the most important issues in stock assessment and management (Bermejo, 2007). The age of fish can be determined using a number of techniques, for example, tag-recapture techniques and measuring change in the modal length of a population over time. However, traditionally fish have been aged by counting seasonally deposited opaque and hyaline (translucent) bands in calcified tissue or structures of fish such as bones, scales or otoliths (Blacker, 1974; Beamish and McFarlane, 1987; Campana, 2001; Bermejo *et al*., 2007).

Otoliths, which are commonly used to age fish, are found in the inner ear of fish and function as part of the auditory and balance systems (Fay and Popper, 2000; Murayama *et al*., 2005). Bands in otoliths form through the differential deposition of calcium carbonate (aragonite) and protein (otolin) during alternating periods of growth (Lang and Buxton, 1993). Narrow opaque bands form in periods of slow or no growth and wider hyaline bands in periods of fast growth (Tesch, 1971). Fish are aged by counting these seasonally deposited opaque or hyaline bands under the assumption that the rate of band deposition, is known or can be validated (Govender, 1995a). Methods of band deposition validation can either be indirect, such as marginal zone analysis (Manooch, 1982), or direct, such as chemical labelling of otoliths (Lang and Buxton, 1993; Campana, 1999; Campana 2001).

While fish can illustrate complex growth, it has been possible to derive growth equations that adequately represent the overall growth patterns of fish (Iles, 1974). Growth rates for fish populations are usually determined from length-at-age data and/or by means of length increment data derived from tag-recapture experiments (Francis, 1988a). It is therefore a common requirement for stock assessment of a fish species to estimate growth parameters using length-at-age or tag-recapture data (Mulligan and Leaman, 1992). More importantly, growth rates for fish populations can provide an indication of, and influence, the sustainable catch of a fish stock (King, 1995, Fennessy, 2000). Faster-growing fish not only mature, reproduce and die earlier (Fennessy, 2000), but those which reach a larger size earlier are able to produce more and larger eggs, thus increasing the chances of larval survival (King, 1995). Faster-growing fish can therefore withstand greater harvesting pressures than slow-growing fish.

While van der Elst *et al*. (1993) and Potts *et al*. (2008) have previously modelled the growth of *Lichia amia* based on length-at-age data, there is little published information on the age and growth of *L. amia* using tag-recapture data. In the studies done by van der Elst *et al*. (1993) and Potts *et al*. (2008), no method was employed to validate the deposition of the growth zones in *L. amia* otoliths. Furthermore, the growth parameters determined by Potts *et al*. (2008) were calculated from *L. amia* caught in southern Angolan waters. In this chapter, the age and growth of *L. amia* off the coast of South Africa is determined, through both the assessment and validation of growth rings in whole *L. amia* otoliths and through the analysis of tag-recapture and length frequency data. The growth parameter estimates determined in this chapter will be used in the following chapter to undertake a per-recruit stock assessment of *L. amia*.

4.2 Materials and methods

General sampling

Researchers at the ORI have undertaken biological sampling of *L. amia* along the South African coastline (primarily in KZN) since 1978. The majority of the samples were collected randomly from recreational catches, which included shore, skiboat and spearfishing competitions. In addition, sampling for juvenile *L. amia* using gill nets took place in estuaries mainly in the Eastern Cape (Swartkops River, Sundays River, Kowie River and Krom River) and to a lesser degree in the Western Cape (Goukamma). In 1992, the ORI utilised some of these data for the preliminary investigation into the age, growth and stock status of *L. amia* (van der Elst *et al*., 1993). However, *ad hoc* sampling was continued after 1992 and the entire data set collected by the ORI including lengths, sex, maturity state and whole *L. amia* otoliths were used for this study. Biological sampling of *L. amia* was thus done on an irregular, opportunistic basis from 1978-2007.

Biological sampling of *L. amia* included measuring the total (TL), fork (FL) and maxillary lengths (ML) of each fish in millimetres (mm) and the total body weight (Wt) of each individual in grams (g). The ML (the length from the tip of the snout to the posterior part of the maxilla) was measured in those cases when only the fish's head was obtained. The ML/FL and TL/FL relationships were expressed by linear regression. The FL/Wt relationship was expressed by the power relationship:

$$Wt(g) = aFL(mm)^b \tag{4.1}$$

where *a* is a scaling constant and *b* is the allometric growth parameter.

Processing and reading otoliths

Sagittal otoliths were removed from the auditory bullae of the *L. amia* sampled, dried with a paper towel and stored dry in gelatine capsules for protection. The capsules were then placed in paper envelopes on which the relevant biological information and sample number were recorded. As *L. amia* otoliths are extremely thin and difficult to section, otoliths were read whole. Using a dissecting microscope and reflected light, the number of opaque bands were counted from the nucleus to the outer margin of the otolith, with one annulus consisting of a wide hyaline zone and a narrow opaque zone. In order to enhance the optical clarity of growth zones, otoliths were submerged in glycerine in a petri dish and observed against a black background. The otoliths were read three times by two readers: reader 1 read the otoliths twice (R_{1+2}) using a magnification of ~15x, and the third reading (R_3) was done simultaneously by reader 1 and a more experienced reader (reader 2) using a stereo dissecting microscope connected to a computer screen. When conducting the third reading if no consensus was reached between reader 1 and 2 on the number of growth rings, the otolith was rejected. In order to avoid inconsistency when determining the position of the first opaque band, measurements were taken when the first opaque band was clearly visible and used as a guideline when viewing otoliths that had less well-defined growth zones. Otoliths were read at least two weeks apart with no reference to the previous readings and without knowledge of the length or weight of the fish. If age estimates did not coincide with the first two readings, the age from the third reading (R_3) was taken as the final age as this was considered to be the most accurate (both readers using a higher resolution screen).

In order to assess the ageing bias between readers for the different otolith readings, an age-bias plot was used (Campana *et al*., 1995; Francis *et al*., 1999; Campana, 2001). In this plot, the two age readings assigned by reader 1 (R_{1+2}) were presented as the mean age with 95% confidence interval (CI) corresponding to each of the age categories reported by reading 1 and 2 from the third reading (R_3). As R_3 was assigned by both readers, and considered more accurate, it was selected as the baseline against which to compare the age estimates from R_{1+2}. Furthermore, the average percent error (APE), co-efficient of variance (CV) and index of precision (D) were calculated to evaluate the precision of the three sets of age readings (Beamish and Fournier, 1981; Chang, 1982; Campana *et al*., 1995). The APE and CV test the reproducibility of age estimates for a particular fish species, whereas the index of precision estimates the percent error contributed by each observation to the average age-class (Chang, 1982).

Validation

Indirect method

Marginal zone analysis (MZA) was used to indirectly validate the annual periodicity of growth zone deposition (Hecht and Smale, 1986). By noting whether the growth zone on the margin of each otolith was either opaque or hyaline, the frequency of each margin was plotted to determine seasonality of zone deposition (Hecht and Smale, 1986). This was done by taking into account that one growth zone was considered to represent a calendar year of deposition.

Direct method

Oxytetracycline (OTC), a chemical label, has been extensively used to determine the periodicity of growth zone deposition in fish (Lang and Buxton, 1993; Campana, 2001; Ewing *et al*., 2007). OTC is incorporated at all sites of calcification in hard structures and thus provides a reference point from which ensuing growth can be determined (Lang and Buxton, 1993). From 2000-2006, a number of *L. amia* (n = 34) were measured, weighed and injected intramuscularly with the recommended dosage for fish in the wild (100 $mg.kg^{-1}$, Lang and Buxton, 1993) and subsequently tagged and released with orange dart tags (Hallprint). Two *L. amia* which were injected with OTC on the 8th June 2000 and 11th June 2001 were recaptured by recreational anglers on the 2nd August 2000 and

9th October 2002 respectively (55 and 485 days at liberty respectively). The length (mm FL) and weight (g) were recorded and the otoliths removed, dried and stored in plastic capsules ensuring minimum exposure to natural light that breaks down the OTC mark. Otoliths were than viewed under reflected ultraviolet light and the position of the fluorescent OTC mark was marked on the otolith. The same otolith was then viewed under normal reflected light to determine the number of opaque and hyaline bands deposited distal to the OTC mark.

Growth model

As the von Bertalanffy growth equation is generally regarded as the most suitable for expressing growth of fishes (Hilborn and Walters, 1992; King, 1995; Haddon, 2001), it was fitted to the observed length-at-age data using the special form of the equation:

$$L_t = L_\infty\left(1 - e^{-K[t-t_0]}\right) \tag{4.2}$$

where: L_t = mean length at age t (mm FL),

L_∞ = asymptotic or theoretical maximum body size (mm FL),

K = growth rate parameter,

t_0 = theoretical age at zero length – usually negative (years),

t = age of fish (years).

When utilizing the special von Bertalanffy equation, L_∞ is interpreted as the average length at the maximum age and the resultant curve represents the average growth of the fish in the population when fitted using the least-squares routine (Haddon, 2001).

Absolute and relative error models associated with the length-at-age data were tested. The residual difference between the observed data and expected data from the fitted curve (i.e. test for homeoscedasticity) and the runs test were used to determine goodness of fit. Standard errors (SE) of the estimates of the parameters from the growth model were evaluated by 1 000 bootstrap iterations at 90% CI. The above analysis was undertaken using a spreadsheet and Microsoft Excel 2007 (Prof T. Booth, Department of Ichthyology and Fisheries Science, Rhodes University). Due to insufficient data, the growth curve was not differentiated between males and females.

In addition, the expected mean body weights were plotted against age. This was done using all available lengths (mm FL) and weights (g), and the von Bertalanffy growth equation for body weight:

$$W_t = W_\infty\left(1 - e^{-K[t-t_0]}\right)^b \tag{4.3}$$

where W_∞ is the asymptotic maximum expected weight and b the allometric growth parameter. This model was fitted using a spreadsheet and minimisation of sums-of-squares routine.

Tag-recapture data

Tag-recapture data for *L. amia* were obtained from the ORI/WWF-SA Tagging Project. The relevant methodology undertaken in the ORI/WWF-SA Tagging Project is described in Chapter 3. The data used in the analyses were derived from those *L. amia* which were tagged and recaptured with recorded lengths that could be verified (Chapter 3). Information from recaptured fish that had no recorded length or indication of which type of length measurement was taken (i.e. TL or FL) were discarded. In addition, the measurements of fish from which negative growth was established were assumed to be inaccurate and discarded. With the remaining tag-recapture data, measurement error was estimated using fish recaptured within thirty days of release (Gillanders *et al*., 2001). Assuming no measureable growth occurred during this period, length-at-recapture should equal length-at-release. The Gulland and Holt (1959) and Fabens (1965) models where then used to generate von Bertalanffy growth functions from the tag-recapture data. Although length-at-age and tag-recapture data are strictly not comparable (Francis, 1988a), when interpreting the differences in annual growth between the data types, the method described by Attwood and Swart (2000) was used after considering the recommendations of Francis (1988a and 1995).

Gulland and Holts' (1959) model allows preliminary estimates of the von Bertalanffy parameters L_∞ and K from growth increments (tag-recapture data) and is based on growth rate declining linearly with length reaching zero at L_∞ under the von Bertalanffy growth function. Growth in mm per year was determined as follows:

$$dFL/dt = a + b.\overline{FL} \tag{4.4}$$

where: $dFL = FL_{rec} - FL_{rel}$

$dt = t_{rec} - t_{rel}$

$\overline{FL} = (FL_{rec} + FL_{rel})/2$

When t equals one year, dFL/dt is the growth per year (mm). FL_{rel} is the length at release (mm), FL_{rec} is the length at recapture (mm), with t_{rel} and t_{rec} the corresponding dates, and $\overline{FL}$ the mean of the release and recapture lengths. By plotting the growth per year of individual fish at liberty for ≥1 year (dt ≥365 days) (Natanson *et al.*, 1999; Natanson *et al.*, 2006) against the $\overline{FL}$, the von Bertalanffy growth parameters were estimated from the linear regression as $L_\infty = -a/b$ (value at x-intercept where $y = 0$) and $K = -b$ (slope).

In order to make the von Bertalanffy curve suitable for use with tag-recapture data, Fabens (1965) re-formulated the von Bertalanffy curve in terms of size increments after a given time from a given initial length (Haddon, 2001):

$$\Delta L = (L_\infty - L_t)\left(1 - e^{-K\Delta t}\right) \tag{4.5}$$

where Δt is the change in time, L_t length at time t and ΔL the change in length. However, on a residual plot the variability of the residuals increase as ΔL increases with initial size (L_t). Thus, when fitting Fabens' (1965) model, a weighted least squares approach or a maximum likelihood method that directly estimates the variance, is required (Haddon, 2001). Francis (1988b) described such a maximum likelihood approach (assuming the residuals are normally distributed) with a number of different functional forms used to describe the relationship between residual variance and expected ΔL. In order to obtain the best possible fit of Fabens' (1965) model, three different functional forms suggested by Francis (1988b) were simulated. These were:

1. an inverse linear relationship between deviation and the expected ΔL:

$$\sigma = \upsilon\left(\Delta\hat{L}\right) \tag{4.6}$$

2. a lognormal standard deviation:

$$\sigma = \tau\left(1 - e^{-\upsilon \Delta \hat{L}}\right) \tag{4.7}$$

3. residual standard deviation which followed a power law:

$$\sigma = \upsilon \Delta \hat{L}^{\tau} \tag{4.8}$$

where υ and τ are constant parameters which are estimated, and σ is the standard deviation. For each error structure, the Fabens' (1965) model was fitted using a spreadsheet and by minimizing the negative log-likelihood (Haddon, 2001):

$$L(\Delta L \,|Data) = \sum_i \left(\frac{1}{\sqrt{2\pi\sigma}} e^{\frac{(\Delta L - \hat{L})^2}{2\sigma^2}} \right) \tag{4.9}$$

For each of the different functional forms suggested by Francis (1988b) for the relationship between residual variance and expected ΔL, the best fit of the model was determined by using Akaike's (1973) information criterion (i.e. $AIC = 2LL + 2p$, where p = number of parameters).

In Fabens' (1965) method, t_0 is redundant and was therefore calculated by solving for t_0 (Eq. 4.2) using L_t = 5.7 mm TL, which is the length at birth (Connell, 2007), t = 0 and the different values of L_∞ and K determined through each method (Gulland and Holt, 1959; Fabens, 1965). This allowed for von Bertalanffy growth curves to be plotted with the growth parameters (L_∞ and K) estimated using the tag-recapture data and other methods.

The von Bertalanffy parameters estimated using the tag-recapture and length-at-age data are not directly comparable (Francis, 1988a). In essence, the parameters estimated from the two data types have different meanings. In particular L_∞, which is the asymptotic mean length-at-age from length-at-age data, but is the maximum length for tag-recapture data. Furthermore, L_t in Eq. 4.2 is the expected length, but in Eq. 4.5 is the observed length, differences in meaning which are often ignored (Francis, 1988a). These differences result in Eq. 4.2 and 4.5 being different models and not simply different formulations of the same model (Francis, 1988a). Francis (1988a), however, recommended re-parameterisation of the von Bertalanffy equation and outlined methods for comparing growth rates determined from the different data types. Francis (1995) makes further recommendations in interpreting differences between growth rates with tag-recapture and length-at-age data when employing Schnute's (1981) growth model to estimate growth parameters from the length-at-age data. In this study, the special form of the von Bertalanffy equation was used and in order to compare the rates of growth from the length-at-age and tag-recapture data, the method described by Attwood and Swart (2000) was applied, which is similar to that in Francis (1995). Using this method, the annual growth rates of the individual tagged *L. amia* were calculated using the following equation:

$$G_i = 365\left(\frac{FL_{i\,rec} - FL_{i\,rel}}{dt}\right) \tag{4.10}$$

where: G_i = growth rate of individual *L. amia* (mm.year^{-1}),

$FL_{i\,rel}$ = length (mm FL) at release,

$FL_{i\,rec}$ = length (mm FL) at recapture,

dt = days at liberty.

For this analysis only fish that had been at liberty for >1 year ($dt \geq 365$) were included. This reduced the effect of measurement error (by avoiding those fish that had negative growth) and the chance of bias caused by seasonal growth variations. G_i values were then plotted against the FL (mm) of individual *L. amia* midway during their time at liberty (Attwood and Swart, 2000). The length midway between release and recapture was estimated as follows:

$$\overline{FL_i} = L_\infty - exp\,\frac{ln(L_\infty - FL_{i\,rel}) + ln(L_\infty - FL_{i\,rec})}{2} \tag{4.11}$$

The estimated L_∞ from the tag-recapture data (Fabens, 1965) was then used when applying Eq. 4.11 to the increment data. In order to compare the growth rates (G_i) determined by the tag-recapture data model and the length-at-age data, the von Bertalanffy growth model was transformed to (Attwood and Swart, 2000):

$$\frac{dFL}{dt} = L_\infty \times K\left(1 - \frac{FL}{L_\infty}\right) \tag{4.12}$$

where L_∞ and K were taken from the length-at-age data. The G_i and dFL/dt values were then compared graphically. A two-tailed, paired *t*-test with critical values selected at 95% CI tested the null hypothesis (H_o) that the estimated annual growth rate determined from the tag-recapture data is no different to the predicted growth rate determined from the length-at-age data. Similar to Gulland and Holts' (1959) model, when plotting the linear regression of the G_i and dFL/dt values, the von Bertalanffy growth parameters were estimated as $L_\infty = -a/b$ (value at *x*-intercept where $y = 0$) and $K = -b$ (slope). The best von Bertalanffy growth parameter estimates from the tag-recapture data, determined using Gulland and Holt's (1959) and Fabens' (1965) methods, where then inputted into Eq. 4.12 and plotted as well.

Length frequency analysis

In addition to determining age and growth using otoliths and tag-recapture data, length frequency analysis using ELEFAN I (Pauly and David, 1981; Pauly, 1990), in the FiSAT II stock assessment package (Gayanilo *et al*., 2005), was conducted to provide a third method to determine von Bertalanffy growth parameters (L_∞ and K). A *K*-scan routine was conducted to assess a reliable estimate of K (Gayanilo *et al*., 2005; Al-Barwani *et al*., 2007). Using the L_∞ and K estimates from these techniques, the growth performance index $\grave{\emptyset}$ was calculated (Pauly and Munro, 1984):

$$\grave{\emptyset} = \log_{10}(K) + 2.\log_{10}(L_\infty) \tag{4.13}$$

These analyses were undertaken using length frequency data obtained from *L. amia* caught in the Kleinemonde Estuary from April 1993 to June 2002 (Dr P. Cowley, SAIAB, unpublished data). This data set forms part of an ongoing monitoring program of the fish of the East Kleinemonde Estuary (Cowley and Whitfield, 2002; James *et al*., 2007). All of the *L. amia* caught in the Kleinemonde estuary were measured using standard length (SL). To obtain the FL (mm) for comparative purposes the FL/SL relationship from Marais and Baird (1980) was used:

$$FL(mm) = 0.785 + 1.047SL(mm) \tag{4.14}$$

Once the von Bertalanffy parameters were estimated from the length-at-age data (Eq. 4.2), the growth performance index (Eq. 4.13) was re-calculated using the L_∞ and K values obtained. The *K*-

scan routine was then re-run with the length frequency data (as described above) and using the L_∞ estimate obtained from the length-at-age data. This allowed for validity and reliability of the growth parameters from the length-at-age data to be tested.

4.3 Results

A total of 231 *L. amia* were sampled along the South African coast between 1978 and 2007, with the majority sampled along the KZN coast, *n* = 123 or 53% (Table 4.1). The remainder of the *L. amia* were sampled along the Eastern and Western Cape coasts (35% and 8% respectively).

Table 4.1: Number of *Lichia amia* sampled along the South African coast (1978-2007).

Region		No. *L. amia*
KZN	Maputaland	2
	Zululand	13
	Greater DBN	104
	South Coast	4
CAPE	Eastern Cape	80
	Western Cape	19
Unknown		9
Total		**231**

The equations describing the length-length and length-mass relationships for *L. amia* obtained from this study are summarised in Table 4.2 with the corresponding graphs in Figure 4.1. Van der Elst (1988) previously expressed the length-mass relationship for larger *L. amia* in KZN waters as:

$$Wt(g) = 7.286 \times 10^{-5} FL(mm)^{2.725} \quad (4.15)$$

Marais and Baird (1980) expressed this relationship for smaller *L. amia* in the South-eastern Cape as:

$$Wt(g) = 1.132 \times 10^{-5} FL(mm)^{3.015} \quad (4.16)$$

When compared to the equations from van der Elst (1988) and Marais and Baird (1980), the equation calculated in this study describing the FL/Wt relationship (Table 4.2) was preferred. This was due to the larger sample size in this study (n = 95) than in the study by Marais and Baird (1980) (n = 50) and because the range in sample sizes was greater in this study than in van der Elst (1988) (based on larger fish in KZN) and Marais and Baird (1980) (based on smaller fish in the Cape).

Table 4.2: The relationships between total and fork length, maxillary and fork length, and weight and fork length for the *Lichia amia* sampled along the South African coast between 1978 and 2007.

Equation	r^2	***n***
$TL(mm) = 1.204\ FL(mm) - 6.762$	0.996	77
$ML(mm) = 0.102\ FL(mm) + 7.496$	0.979	96
$Wt(g) = 1.124 \times 10^{-5}\ FL(mm)^{3.015}$	0.988	95

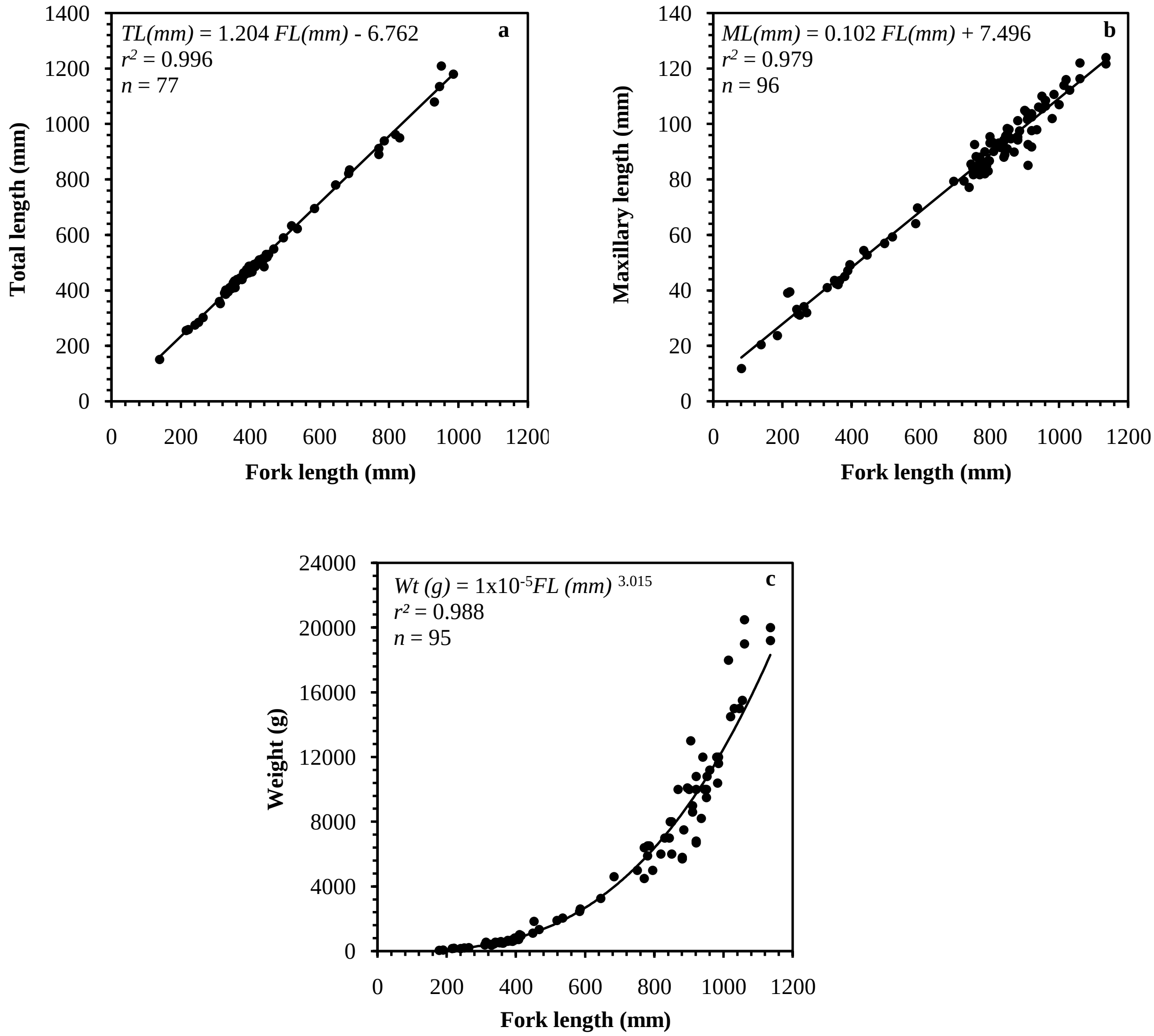


Figure 4.1: The relationship between total and fork length (a), maxillary and fork length (b), and weight and fork length (c) with corresponding equations.

The length and weight frequencies of the 231 *L. amia* sampled are illustrated in Figures 4.2a and b respectively. The *L. amia* sampled ranged in length from 82 to 1 135 mm FL and the heaviest fish sampled weighed 20.5 kg (1 060 mm FL). Unfortunately few *L. amia* ranging in size from 500-700 mm FL, or 2-4.5 kg, were sampled (Figure 4.2a and 4.2b).

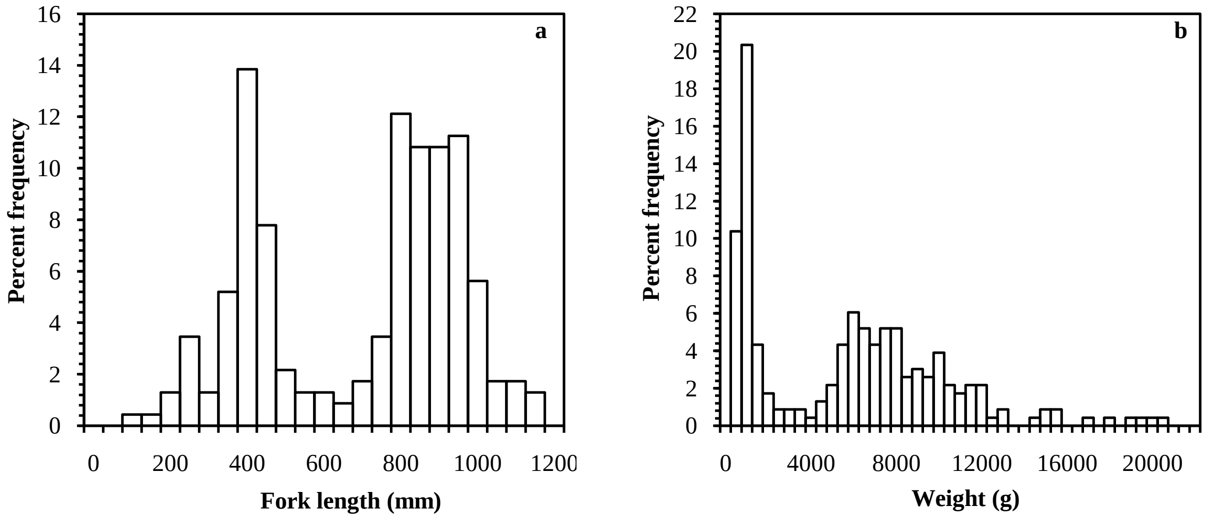


Figure 4.2: Length (a) and weight (b) frequency histograms of *Lichia amia* sampled along the South African coast between 1978 and 2007 (n = 231).

Otolith ageing

Of the 216 pairs of otoliths that were obtained and read, 10 (4.2%) were discarded as they were either too transparent or broken and thus discarded. Useful age estimates were therefore obtained from 206 pairs of otoliths. A photomicrograph of whole *L. amia* otolith is shown in Figure 4.3.

The comparison of the mean of the R_{1+2} ages with the R_3 age estimates, indicates little bias (Figure 4.4). However, the mean of the R_{1+2} age estimates tended to be slightly lower (under-aged) than the R_3 age estimates. This is especially evident for older *L. amia* (≥5 years) with the mean age difference between R_{1+2} age estimates and R_3 age estimates being -1.14 years. Nevertheless, a high correlation between the mean of the R_{1+2} age estimates and the R_3 age estimates still existed (i.e. r^2 = 0.99). An APE of 6.8% and a CV of 8.1% was calculated for the three sets of age estimates (Figure 4.4). The index of precision was calculated at 4.7%. These values were more precise than the values estimated for many other linefish species off the coast of South Africa (Govender, 1994; van der Walt, 1995; Mann *et al*., 2002a).

Figure 4.3: Photomicrograph of a whole *Lichia amia* otolith showing six opaque rings (18x magnification) viewed under reflected light with a black background.

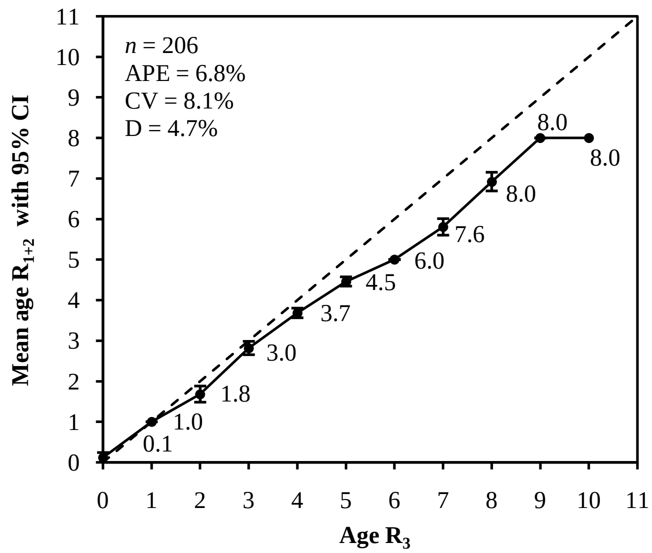


Figure 4.4: Age-bias plot for inter-reader comparison. Error bars represent 95% CI about the mean age assigned by reader 1 during readings 1 and 2 (R_{1+2}) compared to reading 3 (R_3). Dashed line illustrating 1:1.

Age estimates ranged from 0+ (138-353 mm FL) to 10 years (1 060 mm FL) (Table 4.3). As only a few *L. amia* were sampled in the size range 500-700 mm FL, a small number of fish were estimated to be 2 and 3 years old (Table 4.3). Furthermore, very few old *L. amia* were sampled with only one at 9 years (1 135 mm FL) and one at 10 years (1 060 mm FL).

Table 4.3: The observed age-length key for *Lichia amia* sampled along the South African coast (1978-2007).

Size Class FL (mm)	Age (years) 0	1	2	3	4	5	6	7	8	9	10	Total
100-199	3											**3**
200-299	4											**4**
300-399	6	25	2									**33**
400-499		18	4	1								**23**
500-599		1	4	1								**6**
600-699			1	3	1							**5**
700-799				6	22	4						**32**
800-899					7	26	13	2	2			**50**
900-999						7	14	12	5			**38**
1 000-1 099								4	4		1	**9**
1 100-1 199									2	1		**3**
Total	**13**	**44**	**11**	**11**	**30**	**37**	**27**	**18**	**13**	**1**	**1**	**206**

Validation

Indirect method

Difficulty was experienced when determining if the marginal zone of the otoliths were opaque or hyaline. As the majority of otoliths used in this study were collected ten or more years ago, the marginal zones of the otoliths had deteriorated. Furthermore, the otoliths of older fish showed stacking of the growth zones, which increased the difficulty of determining the marginal zones of these otoliths. However, from the otoliths with distinguishable zones, it was evident that the margins were opaque throughout the majority of the year (except Jan). Additionally, it is evident that the monthly sample size was smaller in the first half of the year (January to June) in comparison to the second half of the year (July to December). This is because the majority (53%) of the *L. amia* were sampled along the KZN coast (Table 4.1), where they are only present from June to November. While 155 of the 206 otoliths were used in the MZA, the above mentioned factors contributed to this method providing weak evidence to support the assumption that one hyaline and one opaque band are deposited annually.

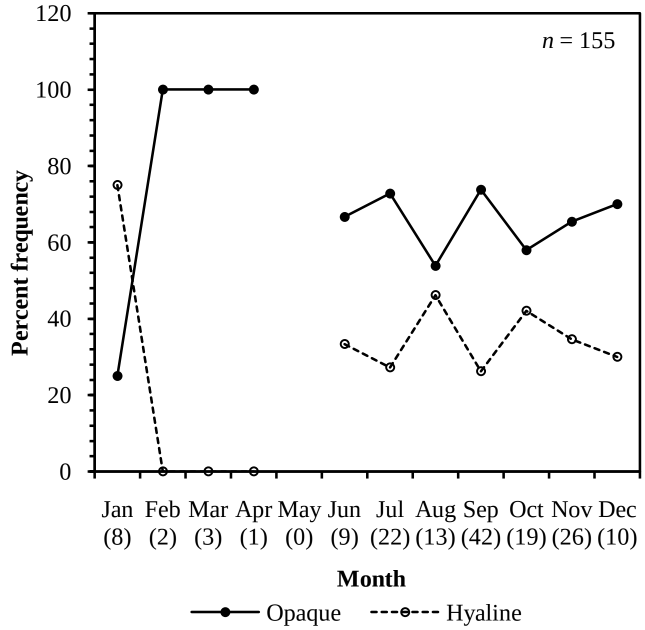


Figure 4.5: Temporal changes in the marginal zone of *Lichia amia* sampled along the South African coast. Numbers in parenthesis indicate sample size of fish collected in each month.

Direct method

The otoliths of the *L. amia* that was at liberty for 55 days had a fluorescent mark close to its edge, with the start of a hyaline band distal to the OTC mark (Figure 4.6). This fish had not been at liberty for long enough to deposit an opaque band distal to the OTC mark.

Unfortunately, the otoliths from the second *L. amia* injected with OTC that was at liberty for 485 days were deformed and transparent making it difficult to see any annuli (Figure 4.7). However, an indistinct fluorescent mark was observed approximately one annulus in from the otolith margin which provides some support for the assumption that one hyaline and one opaque band are deposited annually.

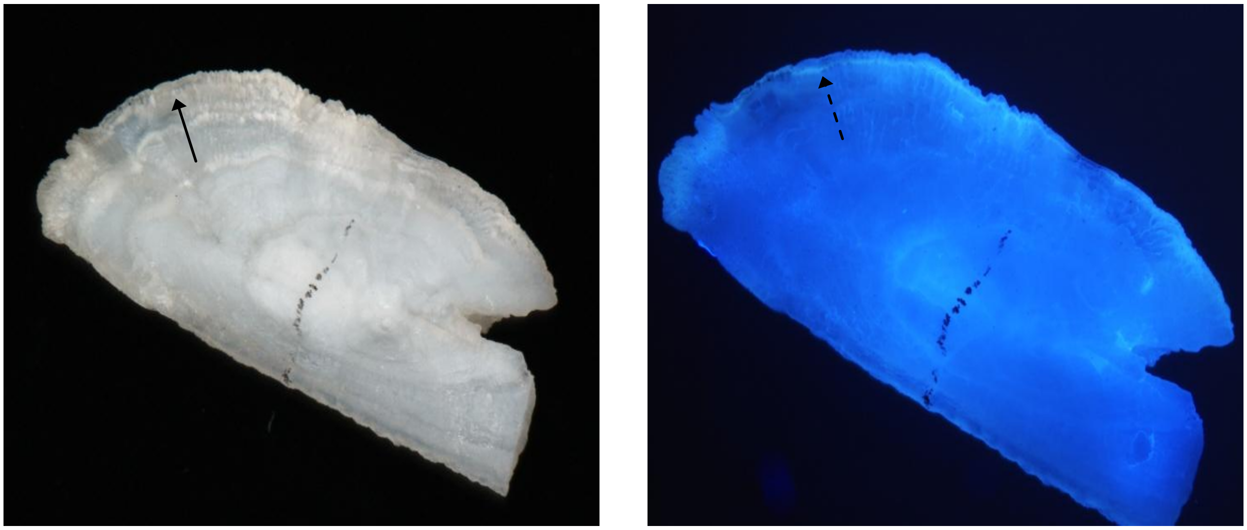


Figure 4.6: Whole otolith from *Lichia amia* injected with OTC viewed under reflected white light (left) and ultra-violet light (right) (16x magnification). Solid arrow indicating opaque band and dashed arrow the OTC mark (days at liberty = 55).

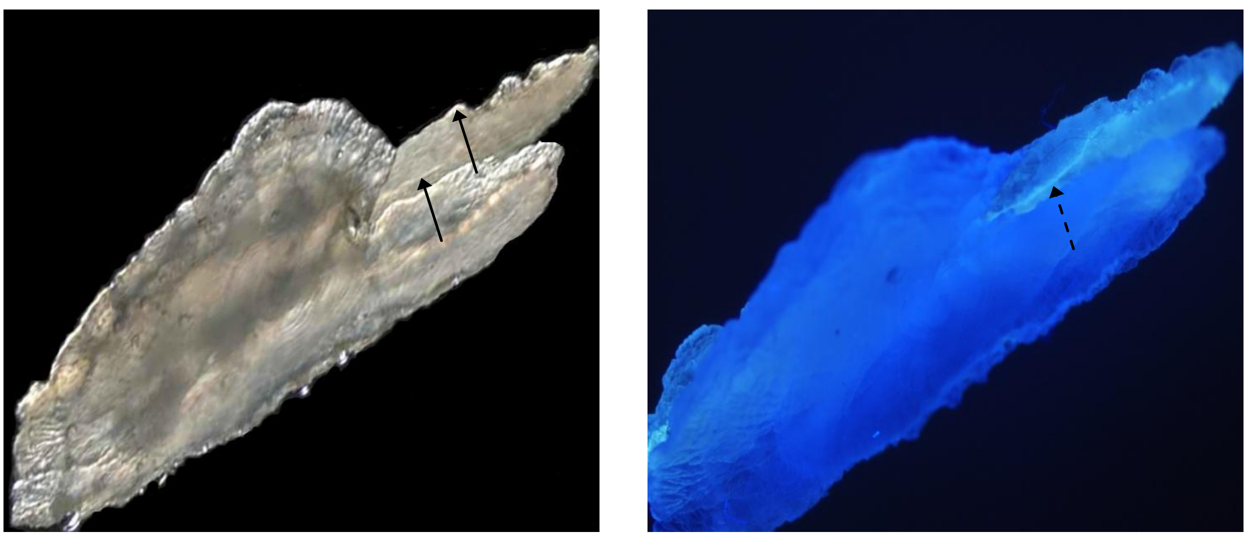


Figure 4.7: Whole otolith from *Lichia amia* injected with OTC viewed under reflected white light (left) and ultra-violet light (right) (16x magnification). Solid arrows indicating opaque bands and dashed arrow the OTC mark (days at liberty = 485).

Growth model

The absolute error model was chosen as it resulted in residuals that were more normally distributed when compared to the relative error model. The runs test was satisfied when fitting the special form of the von Bertalanffy growth equation to the observed length-at-age data, and homeoscedasticity was achieved (Figure 4.8). Table 4.4 summarises the parameter estimates obtained when fitting the special von Bertalanffy growth curve to the observed length-at-age data. Relatively low CV and CI values indicate good estimation of the growth parameters. The fit of the special von Bertalanffy growth curve using the obtained parameters is shown in Figure 4.9.

Table 4.4: The von Bertalanffy growth parameters, standard deviation, CV's and 90% CI's of *Lichia amia* as determined from otoliths.

Parameter	Value	Std dev	CV	Lower 90% CI	Upper 90% CI
a	0.20	0.02	0.09	0.16	0.23
b	Fixed (1)	-	-	-	-
L_1(mm, *t* = 0 years)	233.50	12.33	0.05	211.21	258.82
L_2(mm, *t* = 10 years)	1 069.86	17.23	0.02	1 038.50	1 105.35
L_∞ (mm FL)	1 206.08	49.14	0.04	1 125.27	1 323.30
K (year^{-1})	0.20	0.02	0.09	0.16	0.23
t_0 (years)	-1.09	0.12	0.10	-1.35	-0.90

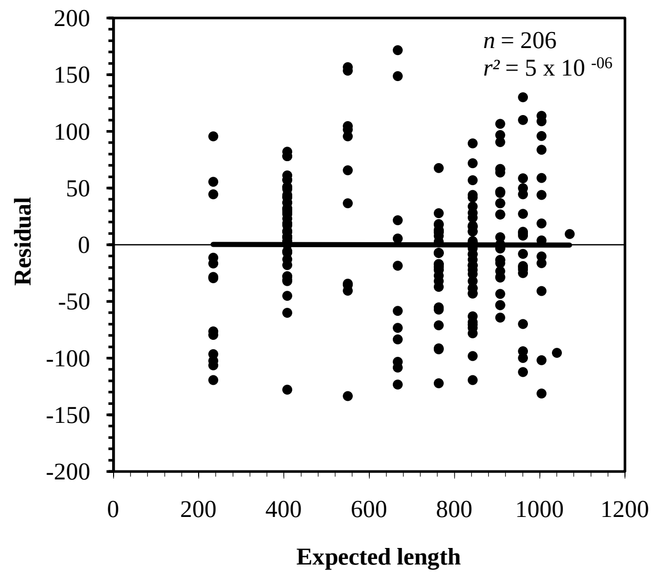


Figure 4.8: Residual plot for expected length (mm FL) obtained using the von Bertalanffy parameters from the *Lichia amia* length-at-age data. (Regression line follows the zero residual on the *y*-axis).

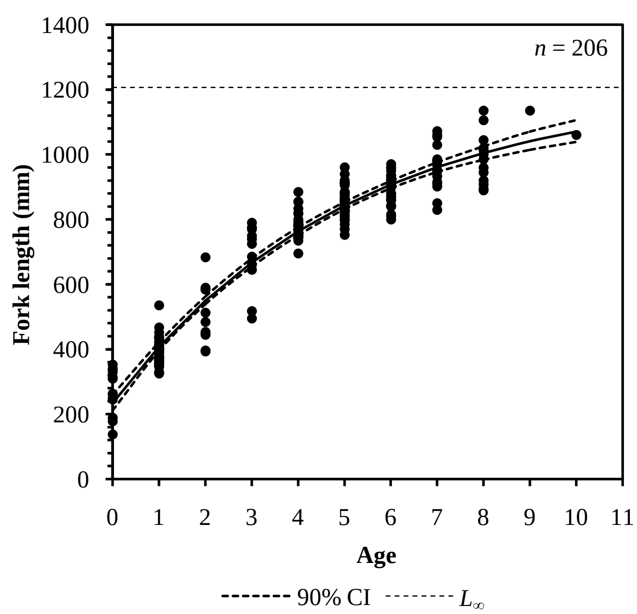


Figure 4.9: The von Bertalanffy relationship between length and age in *Lichia amia* sampled along the South African coast.

The average growth of the *L. amia* population off the South African coast was therefore described as:

$$L_t = 1\,206\,mmFL\left(1 - e^{-0.20[t+1.10years\,]}\right) \tag{4.17}$$

The growth of *L. amia* (in weight) was described by the equation:

$$W_t = 22.1kg\left(1 - e^{-0.19[t+1.10years\,]}\right)^{2.9} \tag{4.18}$$

and is shown in Figure 4.10.

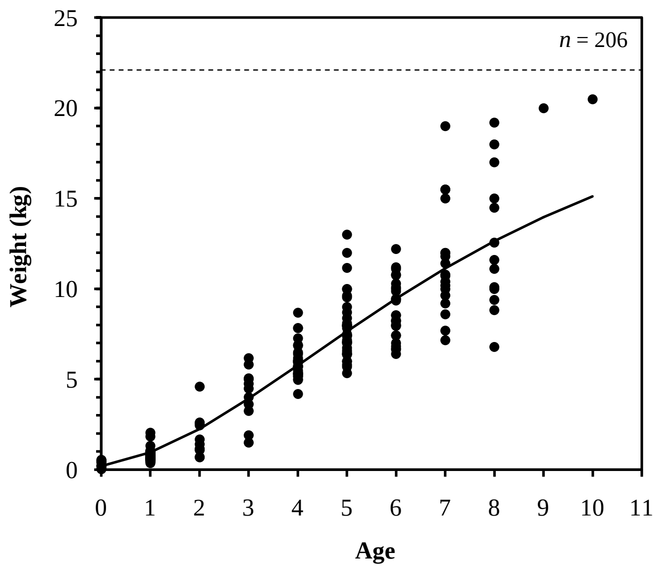


Figure 4.10: The von Bertalanffy relationship between weight and age in *Lichia amia* sampled along the South African coast. Dashed line illustrates W_∞.

Both procedures undertaken to estimate growth in terms of length and weight produced biologically realistic L_∞ and W_∞ values (1 206 mm FL and 22.1 kg respectively). The calculated W_∞ was only slightly larger than the heaviest *L. amia* sampled at 20.5 kg (1 060 mm FL) but was smaller than the South African angling record which stands at 32 kg (van der Elst, 1988). Similarly, L_∞ was only slightly larger than the *L. amia* sampled with the maximum length (1 135 mm FL).

Tag-recapture data

At the end of 2006, 6 456 *L. amia* had been tagged and 457 (7.08%) recaptured along the South African coast (Chapter 3). However, the length data for only 4 429 of these fish could be verified. While the size at tagging ranged from 175 to 1 130 mm FL, the majority of fish tagged were below 587 mm FL (i.e. minimum legal size limit) and relatively few older, mature (800 mm FL) fish were tagged (Figure 4.11a). Unfortunately, the length data for only 145 recaptured *L. amia* (31.7%) could be verified and were used for the estimation of growth. Time at liberty ranged from 1 day to 8.87 years and size at recapture ranged from 260 to 1 109 mm FL (Figure 4.11b) with the majority of fish smaller than 800 mm FL (length at 50% maturity).

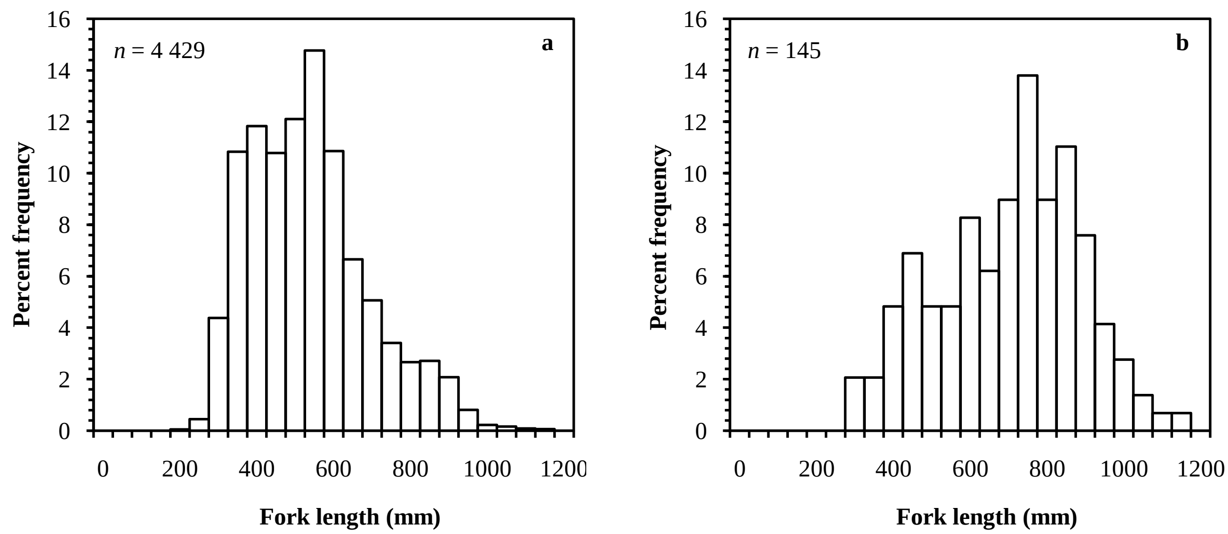


Figure 4.11: Length frequency histograms of *Lichia amia* tagged (a) and recaptured (b) along the South African coast between 1984 and 2006.

The frequency distribution of fish at liberty <30 days showed the majority of taggers (63%) had no measurement error, and that there was as much chance of taggers underestimating the length of fish as overestimating the length of fish (Figure 4.12). The mean difference between recapture and release size was -0.37 mm (±1.50 SE), suggesting that the bias in fish measurements was small relative to the size of the tagged and recaptured fish.

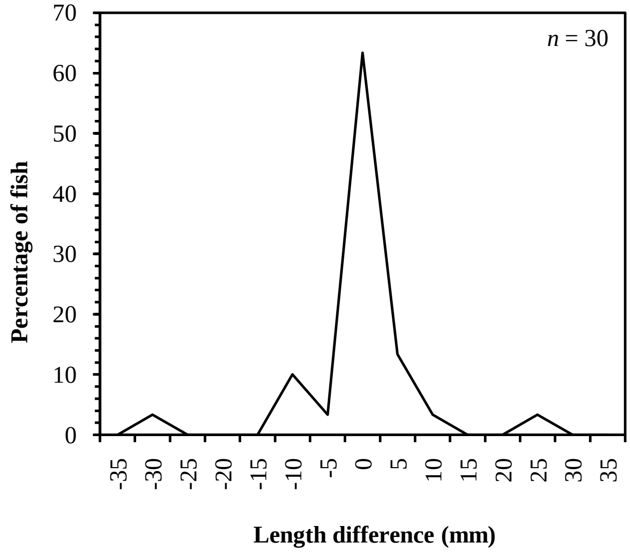


Figure 4.12: Distribution of differences in length between tagging and recapture for *Lichia amia* recaptured <30 days after initial release.

Using Gulland and Holt's (1959) method, the von Bertalanffy growth parameter estimates based on the tag-recapture data were L_∞ = 1 203.6 mm FL and K = 0.250 year^{-1} (Figure 4.13).

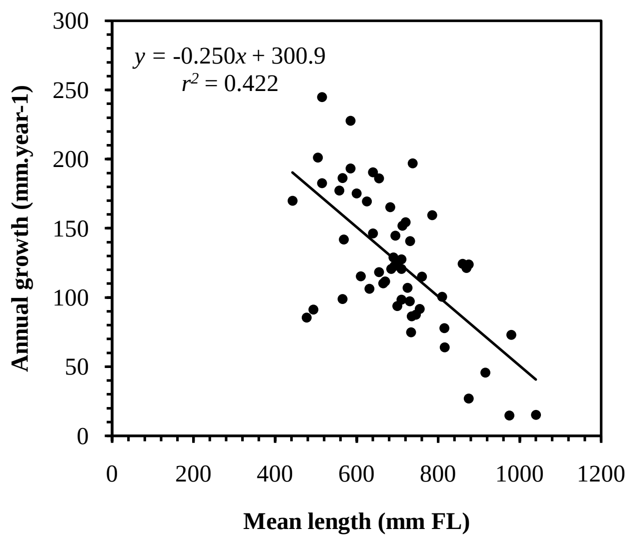


Figure 4.13: Annual growth rates of recaptured *Lichia amia* using Gulland and Holt's (1959) method.

The von Bertalanffy growth parameter estimates using Fabens' (1965) method for the three different functional forms from Francis (1988b) are illustrated in Table 4.5. The parameter estimates are all very similar with similar negative log-likelihood values, especially the lognormal and power law forms. The best fit to the model, as determined using Akaike's (1973) information criterion, was obtained using the power law, where: L_∞ = 1 131.54 mm FL and K = 0.284 year^{-1}.

Table 4.5: Different parameter estimates and AIC values using Fabens' (1965) method for different functional forms suggested by Francis (1988b) with calculated t_0 values.

Functional form	**Parameters**				**-ln*l***	**No. of parameters**	**AIC value**	**t_0 (years)**
	L_∞	**K**	**v**	**τ**				
Inverse linear	1 205.21	0.21	0.71	N/A	710.13	3	1 426.27	-0.018
Lognormal	1 126.83	0.29	0.71	0.67	684.91	4	1 377.82	-0.015
Power law	1 131.54	0.28	1.72	0.70	684.64	4	1 377.28	-0.015

By solving for t_0 for each of the different methods and functional forms (Table 4.5), von Bertalanffy growth curves could be plotted for the different parameter estimates obtained using the tag-recapture and length-at-age data (Figure 4.14). The similarities between the growth curves of the different functional forms are evident, with exception of the lognormal curve which has the highest L_∞ and lowest K (Table 4.5) resulting in a more gentle slope. The Gulland and Holt (1959) parameter estimates produced a curve similar to the others estimated with the tag-recapture data (t_0 = -0.016 years), but a larger L_∞ resulted in the curve extending past the other curves.

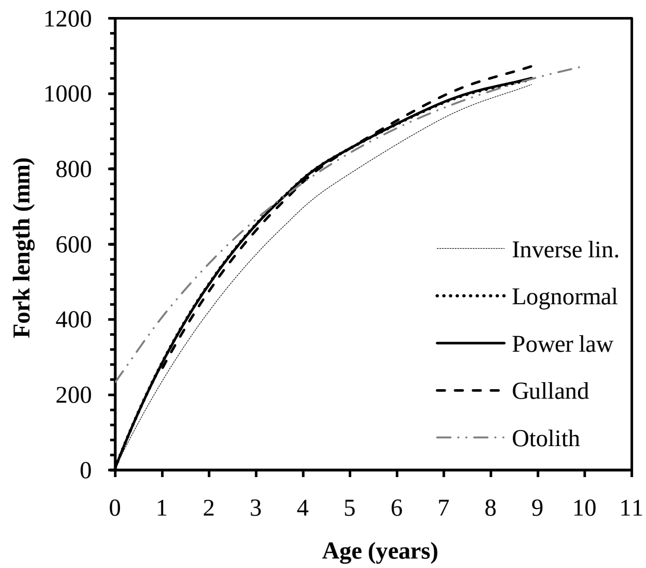


Figure 4.14: Von Bertalanffy growth curves fitted to the tag-recapture and length-at-age data.

Although the estimates of L_∞, using Gulland and Holt's (1959) and Fabens' (1965) methods were similar and biologically realistic, the growth curve using Fabens' (1965) and the residual deviation following a power law (Francis, 1988b), were considered more reliable. This was due to the use of the entire available tag-recapture data set for the Fabens' (1965) model, as suggested by Natanson *et al*. (2006), and because the L_∞ estimated was very similar to the largest *L. amia* tagged (1 130 mm FL). De Bruyn and Murua (2008) also found Fabens' (1965) model with the residual deviation following a power law (Francis, 1988b) to be more reliable. Furthermore, according to Sundberg (1984), estimates of L_∞ and K using Fabens' (1965) model are generally more accurate than those formulated by Gulland and Holt (1959). The limited number of samples, size range and time at liberty when undertaking this method, as well as the high variability in annual growth, would have contributed to inaccuracy in the growth predicted (Natanson *et al*., 2006). Thus, further analysis was based on the estimates using Fabens' (1965) method.

The von Bertalanffy growth parameters estimated using the method described by Attwood and Swart (2000) resulted in a L_∞ = 1 281 mm FL and K = 0.225 year^{-1}. A comparison of the annual growth rate (G_i) using the length-at-age and tag-recapture data (Attwood and Swart, 2000), resulted in the all of the estimated growth rates from the tag-recapture data lying above the values predicted by the growth model based on the otolith age estimates (Figure 4.15). The paired t-test revealed that this difference was, significant (p<0.05) and the null hypothesis (the estimated annual growth rate determined from the tag-recapture data is no different to the predicted growth rate determined from the length-at-age data) was rejected at the 95% confidence level ($p = 5.17 \times 10^{-11}$, t (2.01) = 8.21).

Expectedly the estimated growth rates, when using the von Bertalanffy parameters obtained from the three methods (Fabens', tag-recapture data and otoliths) all decrease with size (Figure 4.15). However, the majority of the estimated growth rates from the tag-recapture data and Fabens' (1965) method lie above the corresponding values predicted by the otolith length-at-age data. Under 910 mm FL, there was a significant difference (p<0.05) and the null hypothesis, that the growth rate determined using the parameters from length-at-age data and those from Fabens' (1965) method were no different, was rejected at the 95% confidence level ($p = 9.19 \times 10^{-18}$, t (2.02) = 14.32), but was accepted for fish ≥910-1 109 mm FL (p = 0.08, t (2.23) = 1.98).

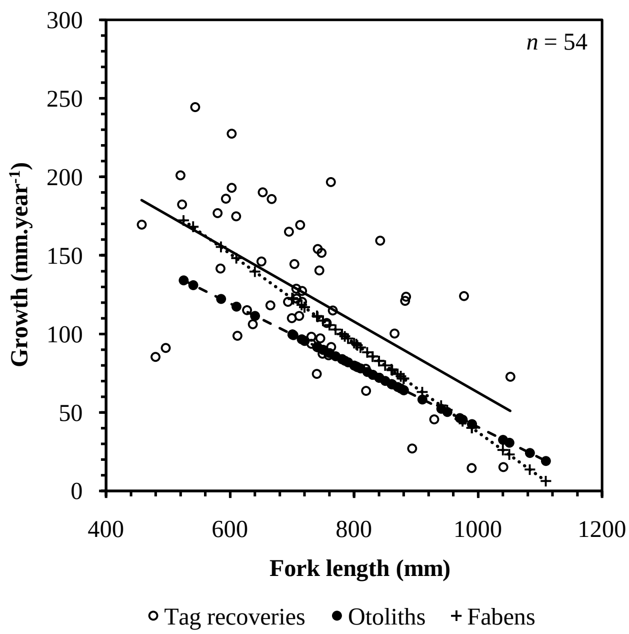


Figure 4.15: The predicted growth rate of *Lichia amia* from tag recoveries, otoliths and from estimates of growth parameters from Fabens' (1965) model.

Length frequency analysis

When analysing the length frequency data from the *L. amia* caught in the Kleinemonde Estuary from April 1993 to June 2002 (Dr P. Cowley, unpublished data) it was not possible to run the entire data set through ELEFAN I. This was because of the low numbers of *L. amia* sampled and because of the uneven time periods between samples. In 1993 however, a relatively large number of *L. amia* were caught (n = 70) ranging in size from 280-570 mm FL (with the majority of fish ranging from 300-400 mm FL) and sampling occurred at least once a month from April-December 1993. The data for each month were pooled and taken as having occurred at the beginning of each month (April-December) and fitted with growth curves by means of ELEFAN I (Figure 4.16). The growth curves meet the modal classes of most samples. The von Bertalanffy growth parameters obtained were L_∞ = 630 mm FL and the best estimated value of K (from the K-scan) was 0.48 year^{-1} with a growth performance index ($\grave{\emptyset}$) of 5.28.

The K-scan routine, when re-run with the length frequency data and a fixed L_∞ of 1 206 mm FL (from the length-at-age data), resulted in a K value of 0.17 year^{-1}. This value is very similar to that estimated from the length frequency data of 0.20 year^{-1}. The growth performance index was calculated as 5.46, which again was very similar to that calculated from the length frequency data.

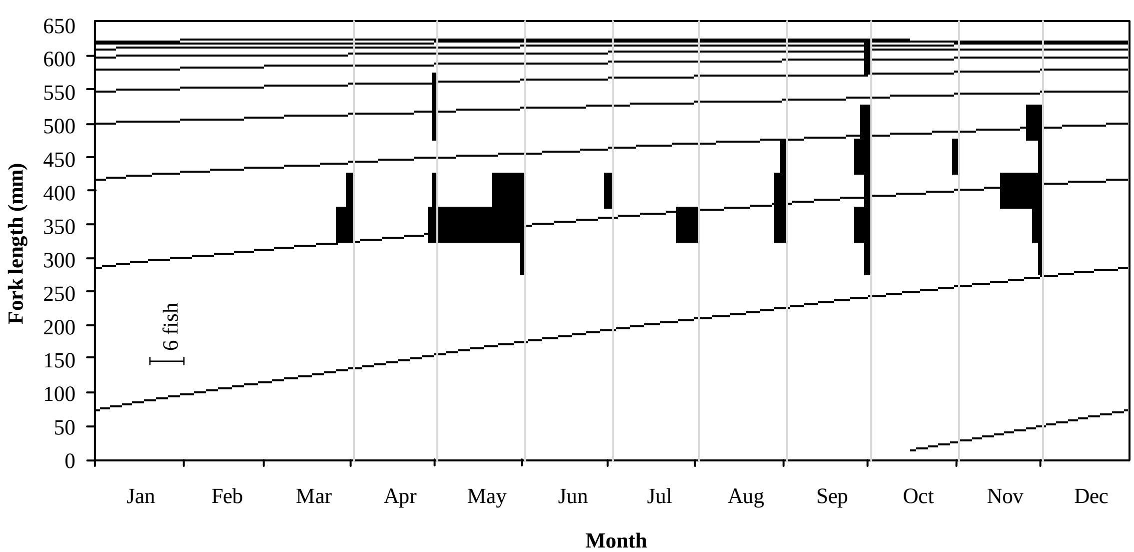


Figure 4.16: Length frequency distribution on the *Lichia amia* caught in the Kleinemonde Estuary during 1993 fitted with growth curves using ELEFAN I (L_∞ = 630 mm FL and K = 0.48 year^{-1}).

4.4 Discussion

The dominance of certain length classes in the fish sampled for otoliths in this study (Figure 4.2) was because of the constraints and methods of biological sampling. With limited funding and man-power, *L. amia* samples were mainly collected along the KZN coast on an opportunistic basis that extended over a period of thirty years (1978-2007). The length and weight ranges of *L. amia* sampled were thus biased and not fully representative of the *L. amia* population distributed along the entire South African coast. By collecting the majority of *L. amia* along the KZN coast, very few fish in the 500-700 mm FL size range were sampled as these fish are more common in the surf-zone of the eastern and southern Cape and are rarely caught in KZN waters. These smaller fish are also close to the minimum legal size limit of 700 mm TL (~4 kg) and anglers that had caught fish of this size (or smaller) would generally not have kept these fish for fear of prosecution. The high frequency of small *L. amia* (<500 mm FL) in the sample (Figure 4.2) resulted from targeted sampling of juveniles in the Goukamma and other Eastern Cape estuaries.

Determining growth of many South African linefish species using otoliths has often proved difficult. Sectioned otoliths have proved more accurate than when reading whole otoliths (Attwood and Swart, 2000; Newman *et al*., 2000; Brouwer and Griffiths, 2004) and thus looking at transverse sections of otoliths for larger fish could prove helpful (Gillanders *et al*., 1999) in the future. However, otoliths of *L. amia* were not sectioned during this study as they are extremely small and delicate, and thus impossible to section with available equipment. The condition of the *L. amia* otoliths used in this study resulted in reduced precision of age estimates and under-ageing of larger *L. amia* occurred. Campana (2001) suggested a CV of 5% should serve as a reference point when aging fish of moderate reading complexity. Although higher than the recommended reference value, the precision of the age estimates obtained in this study were still regarded as satisfactory as they were more precise than those achieved in many other studies on South African linefish (Govender, 1994; van der Walt, 1995; Chale-Matsau *et al*., 2001; Mann *et al*., 2002a; James *et al*., 2003).

The constraints and methods of sampling meant that when undertaking the MZA, data collected over the thirty-year period were combined into a ‘synthetic’ year (Radebe *et al*., 2002). During the sampling period (1978-2007), the growth rate of *L. amia* could have changed and as a result, this study could not account for interannual variability in the growth rate and effects of changing environmental conditions on the growth rate of *L. amia*. Although more suitable for a growth study, ethical considerations deemed it undesirable to sample a large number of *L. amia* over a shorter period. The deteriorated otoliths and biased sampling methods resulted in the MZA (an indirect method of validation) providing only weak evidence to support the assumption that one hyaline and one opaque band is deposited annually. In future studies on *L. amia*, it is recommended that otoliths from more recent samples should be used (e.g. those collected during this study proved easier to age) and if possible samples should be taken on a monthly basis along the entire South African coast (i.e. not region specific).

When aging *L. amia* off the South African coast, van der Elst *et al*. (1993) showed this species to be fast growing, reach a maximum age of nine years and a theoretical maximum length of 940 mm FL. More recently, off the southern coast of Angola, Potts *et al*. (2008) showed *L. amia* to reach a maximum age of eleven years and described the growth as: $L_t = 1\ 137 mmFL(1 - e^{-0.22[t+1.50 years]})$. Similarly, the current study showed *L. amia* to grow relatively fast, reach a slightly larger L_∞ (1 206 mm FL) and a maximum age of at least ten years. Considering that the maximum record weight of *L. amia* in South Africa is 32 kg (van der Elst, 1988) and the largest specimen aged was 20.5 kg (1 060 mm FL), it is likely that the maximum attainable age off the South African coast is over ten years. The L_∞, K and maximum age obtained in this study were similar to those of other Carangid species of similar size (Table 4.6).

Table 4.6: Von Bertalanffy parameters and other life-history characteristics of other Carangid species of similar size to *Lichia amia*.

Species	**Max age (years)**	L_∞	**K (year^{-1})**	**Study**
Caranx ignobilis	>10	1 838 mm SL	0.111	Sudekum *et al*. (1991)
Caranx melampygus	-	897 mm SL	0.233	Sudekum *et al*. (1991)
Seriola lalandi	9	1 252 mm FL	0.189	Gillanders *et al*. (1999)
Elagatis bipinnulata	-	930 mm SL	0.210	Iwasaki (1995)

Van der Elst *et al*. (1993) fitted a logistic growth curve to the length-at-age data for *L. amia* and thus had different parameter estimates to those found in the current study. The different parameter estimates found by Potts *et al*. (2008) may be due to a number of factors. Different growth rates for separate populations could be expected because of different mortality rates and genetic variations (Dutka-Gianelli and Murie, 2001). With the likelihood of separate *L. amia* stocks off the South African and Angolan coasts, different growth rates may result because of such variations. Further research and genetic analyses will be able to determine whether these are in fact separate stocks. In addition, one cannot rule out other factors, such as differences in prey availability and environmental conditions (e.g. water temperature off the southern Angolan coast in comparison to that off the South African coast) as further contributors to the differences found. The different maximum size of *L. amia* sampled, under-aging and inconsistency in the position of the first growth ring (resulting in varying t_0 values) when aging fish in this study could also have contributed to the slight differences in L_∞ and K estimates. Finally, it is also likely that differences in growth rates occur between male and female *L. amia*, as males mature at a smaller size than females (van der Elst *et al*., 1993). Unfortunately, this could not be tested in the current study because of the small sample size. Thus, with a sex ratio of 1M:1.9F off the Angolan coast (Potts *et al*., 2008) and 1M:1F off the South African coast (van der Elst *et al*., 1993), it is possible that the different M:F ratios would have resulted in slightly different growth parameter estimates.

Unlike the otolith based length-at-age data, the length frequencies from the tag-recapture data (Figure 4.11) better represent the *L. amia* population off the South African coast. What is evident, however, is that juvenile (<800 mm FL) *L. amia* dominate the number of fish tagged and recaptured (Chapter 3). This is largely because of the high fishing effort in eastern and southern Cape estuaries where large numbers of juvenile *L. amia* are tagged (B. Mann, ORI, *pers. comm.*). Realistic values for L_∞ and K, using Fabens' (1965) method and residual standard deviation following a power law (Francis, 1988b) were achieved when analysing this data. Growth from this and the otolith based length-at-age data are strictly not comparable and can be misleading, but are useful for a comparison of the growth rate of fish in specific size classes (Francis, 1988a). Working on *Seriola lalandi*, a similar sized Carangid to *L. amia*, Gillanders *et al*. (1999) found comparable results when considering the growth between length-at-age and tag-recapture data. As in this study, Gillanders *et al*. (1999) found tag-recapture data indicated faster growth rates for smaller *S. lalandi* (550-750 mm SL), but once larger, the length-at-age data indicated faster growth (>750 mm SL).

The differences between the estimated growth using the tag-recapture and length-at-age data may be ascribed to a number of different factors. These include the under-aging of older *L. amia*, the influence of tags on growth, inter- and intra-annual differences in growth and variations in year-class strength (Gillanders *et al*., 1999). The faster growth rate, indicated by the tag-recapture data for *L. amia* <910 mm FL, would have resulted from the dominance of juveniles in the tag-recapture data. Smaller fish are expected to grow faster than larger fish, and the lack of older fish in the tag-recapture data would explain the faster growth rate indicated by the length-at-age data for those *L. amia* ≥910 mm FL. Furthermore, the derivation of the von Bertalanffy parameters and the relatively small sample size of tagged and recaptured *L. amia* with usable lengths could also have contributed to the observed difference in growth rates between the two methods.

Estimating growth from tag-recapture data is not without fault. Bias can be introduced because of measurement errors of tagged and/or recaptured fish. Growth can also be depressed because of the physiological effect of external tags (i.e. growth is depressed because of irritation from the tag itself) and/or growth is depressed because of the effects caused during capture and tagging (Attwood and Swart, 2000). Surprisingly, taggers were found to have very little measurement error when it was calculated using fish at liberty for <30 days (Gillanders *et al*., 2001). Furthermore, using the method described by Attwood and Swart (2000), the consistently faster growth apparent for most tagged *L. amia*, it is suggested that external tags did not have the same effect on depressing growth of tagged *L. amia,* as has been found for a number of other linefish species (Attwood and Swart, 2000; Brouwer and Griffiths, 2004). As a robust fish with a high recapture and tag retention rate (Chapter 3), and with high growth rates estimated from the tag-recapture data by all methods, it is reasonable to assume dart tags do not significantly depress the growth of *L. amia* and tagging is thus considered a suitable method for studying growth rates of *L. amia*. This is particularly evident when considering that the majority of *L. amia* tagged where smaller fish (Figure 4.11a), which one would expect to be more susceptible to the effects of tagging (e.g. Attwood and Swart, 2000).

Juvenile fish (300-400 mm FL) dominated the length frequency data from *L. amia* sampled in the Kleinemonde Estuary. A low L_∞ and an exceptionally high growth rate (K) resulted from the analysis using ELEFAN 1. Due to this, the resultant parameters are more suited to describe the growth of juvenile *L. amia* that fall in the size range of fish sampled in the estuary. Despite this bias, the similar values of growth performance ($\acute{\emptyset}$) estimated from the length frequency and length-at-age data, as well as the K values estimated using the K-scan routines, the different growth parameters are in fact comparable. This confirms the validity and reliability of using length-based analysis of growth to compare against other methods (Pauly, 1979).

The growth rates determined in this study are important in providing an indication of the vulnerability of the *L. amia* stock off the South African coast. As a fast growing fish, *L. amia* not only mature, reproduce and die at a relatively young age, but also reach a large size rapidly enabling the production of more and larger eggs, thus increasing the chances of larval survival. Thus, the rapid growth rate and relatively early attainment of sexual maturity should enable the *L. amia* stock to withstand higher fishing pressure than slow-growing, late maturing fish. Van der Elst *et al.* (1993) considered these life history parameters advantageous in maintaining the stock of *L. amia* off the South African coast. The per-recruit stock assessment conducted for *L. amia* off the South African coast, in the following chapter of this study (Chapter 5), will use the new growth parameter estimates (L_{∞}, K and t_0) as determined from the length-at-age data. Furthermore, because the length frequency distribution from the tag-recapture data is more representative of the *L. amia* catch off the South African coast, the stock assessment will incorporate the lengths of tagged *L. amia*.

CHAPTER 5
Per-recruit Assessment

5.1 Introduction

Stock assessment is the processes whereby biological and statistical information are collected and analysed in order to determine changes in abundance of fish stocks (FAO, 1998). In South Africa, most stock assessments of linefish species have been undertaken using per-recruit models (Smale and Punt, 1991; Buxton, 1992; Punt, 1993; Punt *et* al., 1993; Govender, 1995b; van der Walt and Govender, 1996; Griffiths, 1997a; Chale-Matsau *et al*., 2001; Fennessy, 2000; Mann *et al*., 2002a) and are recommended in the Linefish Management Protocol (LMP) (Griffiths *et al*., 1999). Although other models exist, such as surplus production models, these require total catch and effort data, which in most cases do not exist (Punt, 1993). When making management decisions based on per-recruit models (also known as yield-per-recruit models), it is essential to consider the spawner-biomass-per-recruit (*SBPR*) relationship (Butterworth *et al*., 1989).

The yield-per-recruit (*YPR*) of a species is the potential yield of fish over their lifetime, calculated per age class. This model describes a population in terms of the biological processes of growth, mortality and recruitment (Beverton and Holt, 1957). Analyses using this approach are aimed at preventing growth overfishing (when the rate of fishing results in a greater loss in weight from total mortality than gain in weight due to growth) and poor yield (Griffiths *et al*., 1999). This is undertaken by trading off the increase in mass of individual fish through growth with the decrease in the cohort size through mortality over time (Beverton and Holt, 1957). Generally the management of a fishery is assisted by evaluating the effects of varying input parameters, such as age-at-first-capture and fishing mortality, on the stock under question. A weakness of the per-recruit model is that it is relatively simple and a number of major assumptions are made. The model assumes that the fish stock under question is in equilibrium (at a steady state) (Beverton and Holt, 1957). For this reason, the *YPR* from a single cohort over its entire fishable lifespan is assumed equal to that from the whole population over a single year. Furthermore, it assumes that recruitment is constant regardless of stock size, and that recruitment and selection follow a “knife-edge” function (Sparre and Venema, 1998).

Plotting *YPR* against fishing mortality (*F*) allows for target levels (or reference points) to be achieved, e.g. F_{MSY} and $F_{0.1}$. F_{MSY} is the level of fishing mortality at which the maximum sustainable yield (*MSY*) is achieved. If recruitment and mortality are assumed constant, F_{MSY} is equivalent to the fishing mortality (F_{max}) at which the maximum *YPR* is attained (Beverton and Holt, 1957). A more conservative approach, $F_{0.1}$ denotes the level of fishing mortality at which the slope of the *YPR* curve is $1/10^{th}$ of the slope when *F* is zero (Gulland, 1968). *YPR* curves in which $F_{MSY} = \infty$, unrealistically suggest infinite *F* can be applied to a stock and in these cases $F_{0.1}$ is considered a more realistic management target (Butterworth *et al*., 1989).

The *YPR* approach is limited in that it under-estimates the effects of fishing on the reproductive potential of the stock, and thus the risk of recruitment overfishing under heavy fishing mortality, is not included (Butterworth *et al*., 1989). The *SBPR* approach was designed to avoid the occurrence of recruitment overfishing. The *SBPR* of a species is the expected lifetime contribution of a recruit at each age in its life to the spawning stock biomass. Generally there is a strong likelihood of recruitment being impaired and subsequent stock collapse once the *SBPR* drops below critical levels of its unfished level ($SBPR_{F=0}$). Studies on a range of species have demonstrated that this critical level is reached once the *SBPR* is reduced to 20-30% of the unfished level (Goodyear, 1989; Clark, 1991; Mace and Sissenwine, 1993; Punt, 1993; Thompson, 1993; Mace, 1994).

The Linefish Management Protocol (LMP) outlines biological reference points representing the state of a fish population for the management of South Africa's linefish species (Griffiths *et al*., 1999). Target and threshold reference points have been set at 40 and 25% of pristine (or unfished) *SBPR* respectively. The target reference point is aimed at providing high yield with low risk of stock collapse, whereas the threshold reference point is the point below which the risk of stock collapse is unacceptably high (Griffiths *et al*., 1999). The LMP further classifies linefish stocks into management categories based on biological reference points derived from *SBPR* models. Stocks are classified as under-exploited when the *SBPR* is greater than 50% of unfished levels ($SBPR_{F=0}$), optimally-exploited when the *SBPR* is between 40-50% $SBPR_{F=0}$, over-exploited when *SBPR* is between 25-40% $SBPR_{F=0}$ and collapsed when the *SBPR* is <25% $SBPR_{F=0}$ (Griffiths *et al*., 1999).

In previous chapters, it has been noted that the limited geographic range of *Lichia amia*, its popularity as a gamefish with all sectors of the recreational linefishery and the degradation of many estuaries (nursery areas) in the Cape, has aroused concern about the stock status of this species.

Furthermore, other than a preliminary investigation conducted by the ORI in 1992 into the age, growth and stock status of *L. amia* (van der Elst *et al*., 1993), relatively little research has been undertaken on the status of *L. amia* off the South African coast. Thus, considering the value of *L. amia* as a recreational species and the need to provide a scientific basis for its future management, the aim of this chapter is to undertake a stock assessment of *L. amia*. In this chapter, the stock status of *L. amia* is assessed using per-recruit models that make use of results from the preceding chapters. This in turn will allow the modelling of various management options (in line with the LMP) in order to provide the scientific basis needed for the improved management of this species.

5.2 Materials and methods

Mortality

As an exploited linefish species, there are two sources of mortality for the *L. amia* population off the South African coast namely, fishing (*F*) and natural (*M*) mortality. *F* is a result of harvesting (all forms of angling) and *M* results from all other natural factors that cause death such as disease, predation, abiotic factors etc. The instantaneous natural mortality rate of *L. amia* was estimated using two methods:

1. The equation provided by Hoenig (1983):

$$\ln(M) = 0.941 - 0.873\ln(t_{max}) \tag{5.1}$$

where t_{max} is maximum age of 10 years (Chapter 4).

2. Pauly's (1980) empirical equation:

$$\log M = -0.0066 - 0.279\log L_\infty + 0.6543\log K + 0.463\log T \tag{5.2}$$

where *T* is the mean environmental (water) temperature (°C) and, because *L. amia* migrate between the colder waters of the Cape and warmer waters of KZN, *T* over the distribution range of *L. amia* was taken to be 19 °C after Christensen's (1980) study on Southern Africa's sea surface temperature. The von Bertalanffy growth parameters (L_∞ = 1 206 mm FL and *K* = 0.20 $year^{-1}$) were estimated from the length-at-age data (Chapter 4). As a requirement of Pauly's (1980) equation, L_∞ was converted to TL from FL using the total length-fork length relationship $TL(mm) = 1.204\, FL(mm) - 6.762$ (Chapter 4). The resultant L_∞ value was then converted from mm to cm. A range of T estimates was used to test the sensitivity of this method to this parameter.

For F to be estimated, the total instantaneous mortality rate (Z) was first estimated by plotting a catch curve for *L. amia* (Butterworth *et al*., 1989). The catch curve was plotted by assigning ages to lengths of tagged fish (Götz *et al*., in press). This was undertaken by using the age-length key (Chapter 4) to transform the length-frequency distribution of the catch into an age-frequency distribution. By plotting the catch curve using the natural log of the number of *L. amia* in each age class, Z was determined from the slope of the descending limb using a linear regression (Ricker, 1975). F was then simply calculated by subtraction: $F = Z - M$. Only those *L. amia* tagged during the past few years (between 2000 and 2006) were considered in order to obtain a more recent estimate of Z and F. With the large number of juvenile fish tagged in comparison to larger fish (Chapter 3), use of the length data of *L. amia* tagged between 2000 and 2006 for construction of a catch curve may be biased. However, in the absence of better data on the age-frequency of the *L. amia* catch and with so many fish tagged along the entire South African coast, it was assumed that the lengths of *L. amia* tagged and released were similar to those caught and killed by anglers.

To provide an alternative estimate of F and Z, the tag-recapture data from the ORI/WWF-SA Tagging Project was used. This data included all *L. amia* tagged and recaptured along the South African coast between 1984 and 2006 (Chapter 3). These two estimates of mortality were calculated using the method described by Govender (1995a), who modified the Baranov catch equation and the exponential decay model (Ricker, 1975) as follows:

$$N_t = N_0 e^{-Zt} \tag{5.3}$$

where N_t is the number at time t, N_0 is the number at time 0 and Z the instantaneous total mortality rate. In order to estimate values from tag-recapture data, the exponential decay model (Eq. 5.3) was modified such that N_0 is the number of fish tagged at t = 0, and thus N_t is the number of tagged fish alive at time t. This change meant Eq. 5.3 estimated the number of tagged fish alive (N_t), and thus at large, at the end of a set time period t (set at 1 year). At the beginning of the following year (t +1):

$$N_{t+1} = N_t e^{-Z} \text{ or } N_{t+1} = N_t e^{-(F+M)} \tag{5.4}$$

Govender (1995a) extended the model to incorporate multiple releases and recaptures (assuming constant mortality) by modifying Equations 5.3 and 5.4. The number of fish tagged at the beginning of the set time interval t is given as T_t, and thus the number of tagged fish at large (alive) at the beginning of the time interval $t + 1$ is:

$$N_{t+1} = T_t e^{-(F+M)} \tag{5.5}$$

Furthermore, at the beginning of time interval $t + 1$ (the next year), when additional fish are tagged and released (T_{t+1}), the number of fish alive would be:

$$N_{t+1} = N_t + T_{t+1} \tag{5.6}$$

The Baranov catch equation (Ricker, 1975) determines the number of fish caught in a given year (C_t) by estimating the proportion of the total mortality during that year that is due to fishing, and multiplies this by the total number dying in that year:

$$C_t = \frac{F}{Z} N_t (1 - e^{-Zt}) \tag{5.7}$$

The expected number of recaptures during the $t + 1$th time interval (R_{t+1}) is then estimated by combining Equations 5.6 and 5.7 and adding the proportion of tags that are reported (β):

$$R_{t+1} = \beta \frac{F}{Z} N_{t+1} (1 - e^{-Z}) \tag{5.8}$$

where $\beta = 0.7$ (Chapter 3). F and Z needed to be estimated from Eq. 5.8, and because the sampling distribution of tag recoveries can be estimated from a Poisson distribution (Hilborn, 1990; Hilborn and Walters, 1992), the probability of the expected number of tag recoveries (R_t, $t = 1...n$), given the observed number of tagged recoveries (O_t), is as follows (Haddon, 2001):

$$P(O_t) = \frac{R_t^{O_t}}{e^{-R_t} O_t!} \tag{5.9}$$

O_t is the actual observed number of tag recoveries at time interval *t* (i.e. each year). The log transformation of Eq. 5.9 then denotes the likelihood (L) of the number of recoveries being reported:

$$L(O_t|R_t) = \frac{R_t^{O_t}}{e^{-R_t} O_t!} \tag{5.10}$$

Fully expanded, the log-likelihood (Haddon, 2001) is:

$$LL(O_t|R_t) = O_t . \ln(R_t) - R_t - \sum_{i=1}^{O_t} \ln(i) \tag{5.11}$$

The negative sum of the log-likelihood (Eq. 5.11) was calculated in Microsoft Excel and was minimized using the optimisation routine SOLVER to obtain the estimates of *F* and *Z*. The 95% confidence limits of the *F* and *Z* estimates were then determined using the likelihood profile in Poptools (Hood, 2008). Discrepancies in the expected recaptures from the observed values were examined using "deviance" (McCullagh and Nelder, 1989) (Eq. 3.9, Chapter 3).

Per-recruit assessment

As recommended by Butterworth *et al*. (1989), the behaviour of the *SBPR* was considered in conjunction with *YPR* when assessing the stock status of *L. amia* off the South African coast. Without reliable long-term catch records, and information on the spawning stock recruitment relationships, *YPR* and *SBPR* models are the most suitable means of evaluating the status of a fish stock (Butterworth *et al*., 1989; Punt, 1993; Appeldoorn, 1996; Griffiths *et al*, 1999).

YPR was calculated as described by Punt (1992) after Beverton and Holt (1957):

$$YPR = \int_0^{\infty} F . N_t . W_t . S_t . dt \tag{5.12}$$

where *F* is the instantaneous fishing mortality rate (assumed to be constant for each age class), N_t is the number at time *t* (Eq. 5.3), W_t is mean mass of a fish at age *t* (derived from Eq. 4.17 and the

FL/Wt relationship determined in Chapter 4 – Table 4.2) and S_t the selectivity, which was assumed to be knife-edge selectivity:

$$S_t = \begin{cases} 0 & if\ t < t_c \\ 1 & if\ t \geq t_c \end{cases}$$

where fish are only vulnerable to fishing after a particular age (Ricker, 1975), i.e. no fish are selected/captured before age-at-first-capture (t_c), and thus $S_t = 0$, while those fish equal to and above t_c are selected ($S_t = 1$).

SBPR was calculated by summing the biomass at each age multiplied by the proportion mature at each age, and biomass taken as the product of the numbers and mean mass of individuals in the age class (Butterworth *et al*., 1989):

$$SBPR = \int_0^\infty F.N_t.W_t.Ma_t.dt \tag{5.13}$$

$$Ma_t = \begin{cases} 0 & if\ t < t_m \\ 1 & if\ t \geq t_m \end{cases}$$

where Ma_t is the knife-edge maturity function with t_m the age at 50% maturity and B_t is biomass. By changing the t_c value at the current rate of fishing mortality ($F_{current}$), the combination of age-at-first-capture and F that maximises yield without reducing the spawning potential of the stock, was determined. The von Bertalanffy growth parameters from the length-at-age data (Eq. 4.17), in Chapter 4, were used as input parameters for the *YPR* and *SBPR* models. Biological reference points expressed in terms of fishing mortality rate were then estimated. These included $F_{0.1}$, F_{MSY}, F_{SB40}, and F_{SB25}, biological reference points as defined by the LMP (Griffiths *et al*., 1999). By running the models with different t_m values, the effect of age at 50% maturity on the reference points was also determined (Mann *et al*., 2002a). All above-mentioned analyses were undertaken and estimates obtained using a spreadsheet and Microsoft Excel 2007.

5.3 Results

Mortality

When using Hoenig's (1983) equation, the instantaneous natural mortality rate (*M*) of *L. amia* was estimated at 0.343 year^{-1}. Using Pauly's (1980) empirical equation a slightly lower estimate of *M* was obtained (0.332 year^{-1}). Although the estimates of *M*, using Hoenig's (1983) and Pauly's (1980) equations were similar, Pauly's (1980) estimate was used because this estimate proved insensitive to changes in water temperature and thus is probably a better estimate of *M* (Mann *et al*., 2002a). Furthermore, it was the method employed by van der Elst *et al*. (1993) and Potts *et al*. (2008) when estimating *M* for *L. amia*.

A large number (*n* = 2 063) of *L. amia* were tagged on the South African coast between 2000 and 2006. The majority of these fish were between 400 and 600 mm FL (Figure 5.1). Using ages 1-8 years, the instantaneous total mortality rate (*Z*) was estimated from the descending limb of the catch curve to be 0.752 year^{-1} (Figure 5.2). Thus, by subtraction and using *M* from Pauly's (1980) equation, the instantaneous fishing mortality rate (*F*) was estimated at 0.421 year^{-1}. Although *L. amia* enter the fishery at age two (corresponding to the minimum legal size limit of 587 mm FL), age one was used as it was the top of the catch curve as recommended by Butterworth *et al*. (1989). While age one fish theoretically have not entered the *L. amia* fishery, as it is illegal to retain them when caught, many under size *L. amia* are kept by anglers in the Cape (W. Potts, SAIAB, *pers. comm*.). As recommended in the methods outlined by Pauly (1984), age 8 was selected as the bottom of the descending limb as fish of age 10 and 12 were poorly represented in the sample.

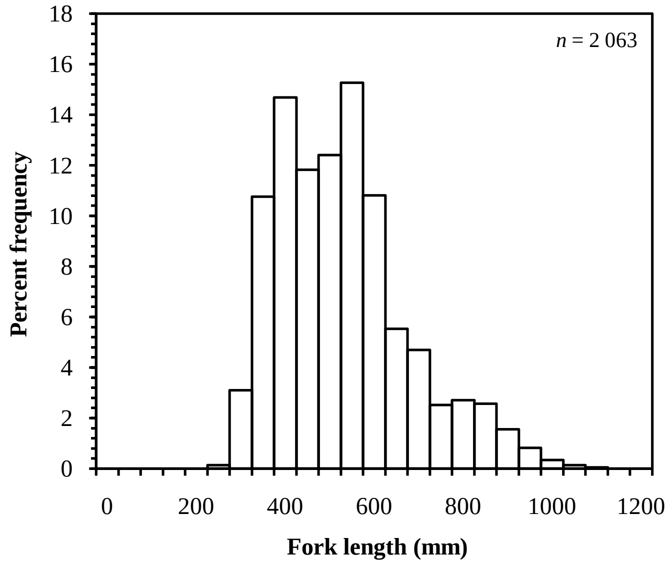


Figure 5.1: Length frequency histogram of *Lichia amia* tagged along the South African coast between 2000 and 2006.

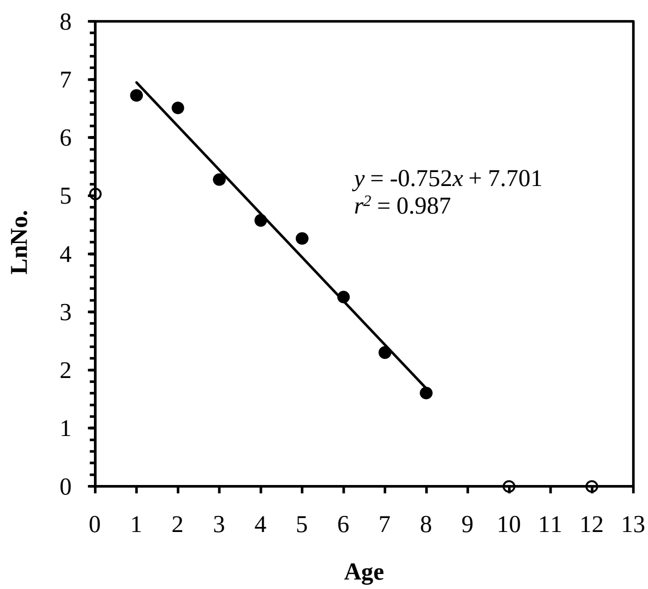


Figure 5.2: Catch curve for *Lichia amia* based on the lengths of fish tagged along the South African coast between 2000 and 2006 (n = 2 063). Solid symbols indicate the points used in the calculation of total mortality.

Both F and Z, estimated using the tag-recapture data, were estimated with relatively narrow 95% Confidence Limits (Table 5.1). With well estimated F and Z values the observed and expected (model-derived) recaptures (Eq. 5.8) were very close to the actual observed recaptures, resulting in low deviance values (Appendix III).

Table 5.1: Mortality estimates for *Lichia amia* from tag-recapture data (1984-2006) with 95% confidence limits.

Mortality	Estimate (year^{-1})	Lower 95% CL	Upper 95% CL
F	0.050	0.046	0.055
Z	0.433	0.393	0.479

Per-recruit assessment

The mortality values derived from the tag-recapture data were largely unrealistic (Chapter 3). The F and Z values obtained were similar to those obtained for a relatively un-fished population of *L. amia* in southern Angola, i.e. F = 0.03 and Z = 0.41 year^{-1} (Potts *et al*., 2008). The model further excludes important parameters such as fishing effort, tag-shedding and tag-associated mortality which may have compromised the results (Griffiths, 1997a; Gillanders *et al*., 2001). Without these parameters, the data violates the assumptions required for more quantitative assessment (Sibert, 1984; Gillanders *et al*., 2001; Shirakihara and Kitada, 2004) (Chapter 3). Furthermore, mortality was estimated with tag-recapture data from the past twenty-three years (1984-2006) and was therefore not applicable to the current situation in the *L. amia* fishery. For these reasons, the input parameters used in generating the per-recruit models were as follows: M = 0.332 year^{-1} (Pauly, 1980), Z = 0.752 year^{-1} (from the catch curve), F = 0.421 year^{-1} ($F = Z - M$), t_m = 4 years, a = 0.00001124 and b = 3.015 (a and b were obtained from the length-weight relationship determined in Chapter 4 – Table 4.2). The age at first capture (t_c) was varied between 2 to 5 years to illustrate the sensitivity of the model to this parameter.

The *YPR* indicated that at the current fishing mortality ($F_{current}$), a t_c of 3 years resulted in the highest yield, whereas a t_c of 5 resulted in the lowest yield (Figure 5.4). The *SBPR* model revealed that for a t_c of two years (= current age at which *L. amia* are first caught and legally retained) and $F_{current}$ =

0.421 $years^{-1}$, the current *SBPR* for *L. amia* is at about 14% of its unfished level or $SBPR_{F=0}$ (Table 5.3). As *L. amia* are relatively fast growing, and mature relatively early, changes in the t_c are reflected as large changes in *SBPR* (Figure 5.4 and Table 5.3).

At the current t_c of two years, $F_{current}$ is substantially higher than F_{SB25}, F_{SB40}, F_{MSY} and $F_{0.1}$ (Table 5.3). A t_c of two years requires the lowest *F* for *MSY* to be reached, whereas at a t_c of 5 years, a slightly higher value of *F* is required (0.390 $year^{-1}$) before *MSY* is reached. F_{MSY} is very similar to F_{SB25} for t_c = 2 and 3 years, and only lower than F_{SB40} for t_c = 5 years. $F_{0.1}$ is lower than F_{SB25} and F_{SB40} for all t_c values, with the exception of F_{SB40} for t_c = 2 years (Table 5.3).

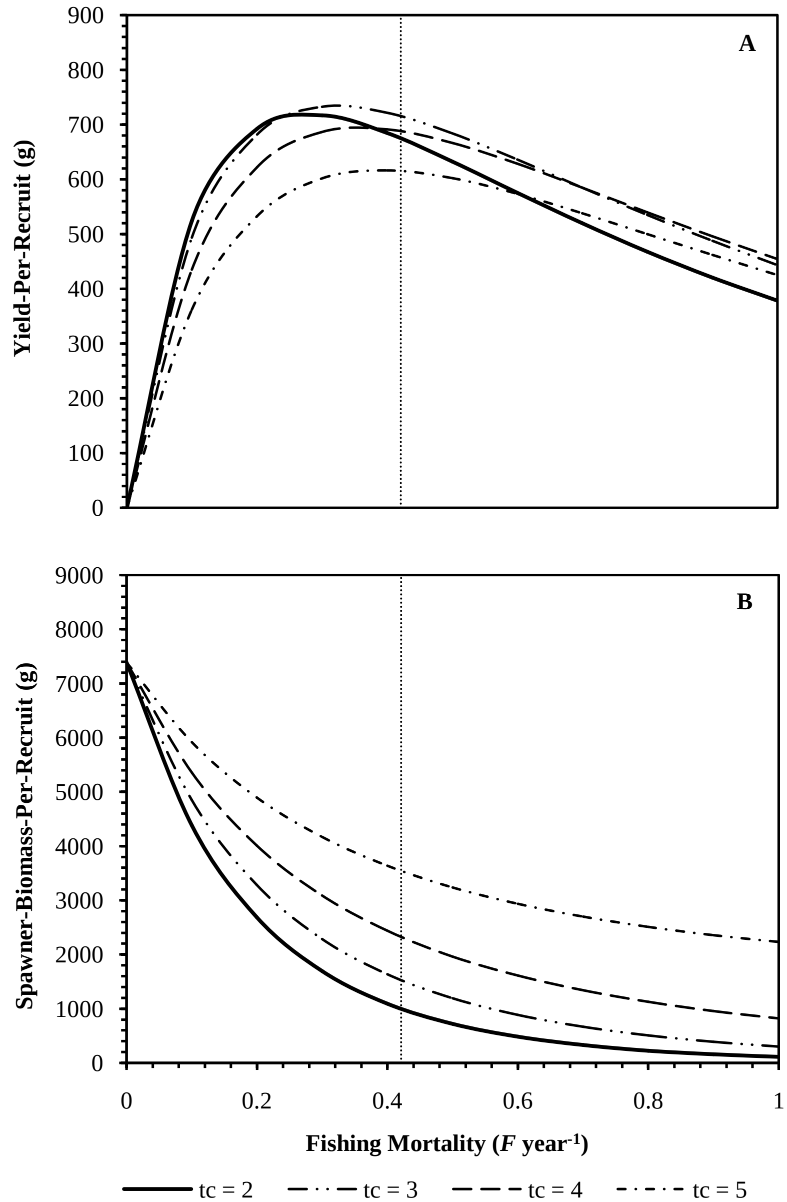


Figure 5.4: Yield-per-recruit (a) and spawner-biomass-per-recruit (b) as functions of increasing fishing mortality (F) for *Lichia amia* along the South African coast, using different values for age-at-first-capture (t_c). Dotted line illustrates $F_{current}$ = 0.421 year^{-1}.

Table 5.3: Biological reference points calculated for *Lichia amia* based on a t_m of four years at different t_c values (years) and $F_{current}$ = 0.421 year^{-1}.

Ref. point	$t_c = 2$	$t_c = 3$	$t_c = 4$	$t_c = 5$
$SBPR_{current}$ (%)	13.56	20.66	31.48	47.95
F_{SB25}	0.281	0.363	0.530	1.523
F_{SB40}	0.180	0.229	0.318	0.592
F_{MSY}	0.278	0.322	0.359	0.390
$F_{0.1}$	0.194	0.223	0.249	0.275

With the uncertainty around the length at 50% maturity of *L. amia* in South African waters (Chapter 3), biological reference points were calculated with three alternative t_m values (Table 5.4). F_{MSY} and $F_{0.1}$ did not change as the age-at-first-capture was fixed at two years for each for each value of t_m. The $SBPR_{current}$, F_{SB25} and F_{SB40} decreased corresponding to an increase in age at 50% maturity.

Table 5.4: Biological reference points calculated for *Lichia amia* based on a set t_c value of two years and with different t_m values (years) and $F_{current}$ = 0.421 year^{-1}.

Ref. point	$t_m = 2$	$t_m = 3$	$t_m = 4$	$t_m = 5$
$SBPR_{current}$ (%)	23.27	18.15	13.56	9.92
F_{SB25}	0.394	0.330	0.281	0.244
F_{SB40}	0.238	0.207	0.180	0.159
F_{MSY}	0.278	0.278	0.278	0.278
$F_{0.1}$	0.194	0.194	0.194	0.194

5.4 Discussion

The greatest weakness of this assessment on the stock status of *L. amia* in South African waters was the absence of length (and thus age) data on the catch. For this reason length data from the ORI/WWF-SA Tagging Project were used as a substitute for actual catch data with the assumption that the lengths of *L. amia* tagged and released off the South African coast were similar to those caught and killed by anglers. This may have resulted in the underestimation of the number of larger fish caught, as taggers are likely to tag undersize fish and retain the bag limit (2 fish/angler/day) of fish over the minimum size limit. The validity of this assumption is difficult to assess but based on the length frequency of the tagged population (Figure 5.1) it was believed to be a reasonable assumption. The high number of juvenile *L. amia* tagged could have contributed to the high mortality values obtained using the catch curve. However, when only using the lengths of *L. amia* recaptured along the South African coast (i.e. data that would not have the same size bias as the tagged fish) a high Z value was still obtained of 0.614 year^{-1}, and at an F value of 0.282 year^{-1} the $SBPR$ was still <25% $SBPR_{F=0}$ (at t_c = 2 years and t_m = 4 years). The $SBPR_{current}$ would thus probably fall within the range of the two estimates (14 - 25% i.e. from the released fish and from recaptured fish).

The estimates of natural mortality determined in this study were similar to those obtained in the studies by van der Elst *et al*. (1993) and Potts *et al*. (2008). In both studies, M was only slightly higher than this study (Table 5.5). Different L_∞ and growth rate (K) values in each study (Chapter 4) would have contributed to this difference, as well as the different water temperatures (T) used in Pauly's (1980) empirical equation. However, even though *L. amia* in southern Angolan waters mature at a smaller size and are exposed to different environmental conditions (Chapter 4), rates of natural mortality are still comparable with those in South African waters (Potts *et al*., 2008). Hoggarth *et al*. (2006) recommend calculating M from lightly fished stocks, which however, is generally not possible. Fortunately, the work done on *L. amia* by Potts *et al*. (2008) provides such an opportunity. Nevertheless, the M obtained using Pauly's (1980) method in the current study was still preferred, as there is a possibility that the *L. amia* off southern Angola represent a different genetic stock. Future research is needed to determine whether this is indeed the case.

Estimates of total and fishing mortality did, however, vary to a far greater degree between the various studies on *L. amia* (Table 5.5). Potts *et al*. (2008) also used a catch curve to calculate Z enabling F to be calculated through subtraction. The resulting Z and F values they obtained were much lower than estimated during this study (Table 5.5). This is expected as the *L. amia* population off the southern Angolan coast is subjected to very little fishing effort (Potts *et al*., 2008). Van der Elst *et al*. (1993) utilized tag-recapture data from the South African coast and calculated a higher F value to that calculated in this study using the tag-recapture data (Table 5.5). However, the uncertainty of the estimates for tag-shedding, tag-associated mortality and questionable rates of tag reporting, in both studies (in this study and van der Elst *et al*., 1993), reduced the accuracy of the mortality estimates. There is clearly a need for future research to determine annual variability of these parameters, not only for *L. amia* but also for other important exploited linefish species, e.g. *Argyrosomus japonicus* dusky kob (Griffiths, 1997a). These estimates could then be incorporated into future studies on the biology and stock status of such species with more confidence than is currently possible.

Table 5.5: Mortality estimates for *Lichia amia* from different studies.

Site and year of sampling	**Mortality estimate (year^{-1})**		
	M	***F***	***Z***
South Africa (1984-1991)[1]	0.37	0.17	0.54
Angola (2005-2006)[2]	0.38	0.03	0.41
South Africa (2000-2006)[3]	0.33	0.42	0.75
South Africa (1984-2006)[4]	0.38	0.05	0.43

1 = van der Elst *et al*. (1993) 3 = this study
2 = Potts *et al*. (2008) 4 = this study (tag-recapture data)

The assumption that all fish below the legal size limit are released (knife-edge selection), would have been violated as some anglers (other than taggers) do retain fish under the legal limit where there is poor enforcement of fishing regulations. In addition, there is a chance that some of these smaller fish (<587 mm FL) do not survive after being released because of poor handling or deep hooking (Bartholomew and Bohnsack, 2005). Furthermore, the assumption of knife-edge maturity would have been violated because individual fish will mature over a range of lengths. However, the use of age at 50% maturity reduces this variability and produces representative results (Sparre and Venema, 1998). Although van der Elst *et al*. (1993) determined length at 50% maturity as 800 mm FL, more recently Potts *et al*. (2008) determined 50% maturity to be 623 mm FL in southern Angola. Revision of the length at 50% maturity of *L. amia* in South African waters should be considered in future research, because with a decrease in age at 50% maturity there was a relatively large increase in the $SBPR_{current}$ (Table 5.4) and would therefore affect management regulations depending on the classification of the stock based on biological reference points (Griffiths *et al*., 1999).

The assumptions of constant mortality and recruitment are difficult to evaluate. *Z* (and therefore *M*) changes with each age class being considerably higher for younger fish (Figure 5.2). Assuming a constant Z for all age classes in a population is an obvious weakness of this type of assessment but, in the absence of better data, is the best estimate that can be made (Punt, 1993; Appeldoorn, 1996). Furthermore, by assuming constant recruitment, natural fluctuations are not accounted for (Gulland and Boerema, 1973). This is particularly problematic when applied to estuarine-dependent species, where both anthropogenic factors and fishing impact on resources (West and Gordon, 1994). Environmental conditions not only play a role in the number of juveniles recruiting into estuaries but also the number of juveniles and sub-adults joining the migrating population (Marais, 1982; Smale and Kok, 1983; Bennett *et al*., 1985; Whitfield and Kok, 1992).

Previously, van der Elst *et al*. (1993) found the *L. amia* stock off the South African coast to be under-exploited (*SBPR* level was >50% $SBPR_{F=0}$),with F_{MSY} and $F_{0.1}$ far higher than in the current study (5.65 and 0.7 year^{-1} respectively). These values of F_{MSY} and $F_{0.1}$ were unrealistically high, and so too the F_{SB50} of 0.66 year^{-1}. This would imply *L. amia* could be placed under high levels of fishing effort with little effect on the stock. The low input value of fishing mortality used by van der Elst *at al*. (1993), estimated using tag-recapture data, would have been the key factor in the results obtained. However, as discussed above and in Chapter 3, it is unlikely the mortality estimate would have been accurate because of the cooperative nature of the tagging project and because of the lack of essential parameter estimates.

A more recent study by Lamberth and Turpie (2003) categorised the *L. amia* population off the South African coast as optimally exploited (between 40-50% of the pristine *SBPR*). However, the study by Lamberth and Turpie (2003) was primarily based on the results from van der Elst *et al*. (1993). Although they used additional indicators of abundance (e.g. reduction of *CPUE* from a historical value), it was not apparent which indicators were applied to the individual species assessed. Furthermore, the study by Lamberth and Turpie (2003) was completed almost ten years after the initial analysis by van der Elst *et al*. (1993), during which time substantial changes in the fishery could have occurred. Therefore, the results from the study by Lamberth and Turpie (2003) are unlikely to have been fully representative of the actual *L. amia* stock status.

In contrast to all previous studies, the *SBPR* model used in this study indicated that the *L. amia* fishery off the South African coast has collapsed, as $SBPR_{current}$ is <25% $SBPR_{F=0}$. This confirms the need for stock rebuilding, as found when applying the indicators outlined in the LMP in Chapter 2, i.e. the reduction of the *CPUE* and catch composition by more than 75% of a historical value. In addition to these indicators, the LMP includes public concern as a further useful stock status indicator. According to the LMP, when more than 75% of respondents class a fish stock as being over-exploited, a necessary decrease in fishing effort is warranted (Griffiths *et al*., 1999). A questionnaire (Appendix II), undertaken following the 2001 South African Marine Linefish Management Association (SAMLMA) meeting, was used to gauge anglers' perceptions on the stock status of *L. amia*. The results of the questionnaire showed that the majority (48%) of the 192 respondents were concerned about the *L. amia* stock decreasing (31% indicated no change, 19% an increase and 2% no response). The respondents belonged to various sectors of the South African linefishery and 54% indicated that they did not target *L. amia*. Of the 46% that targeted *L. amia*, more than half (58%) perceived the stock to have decreased. Further separation of the respondents into provinces, showed that of the respondents that target *L. amia* in KZN, 75% perceived the *L. amia* stock had decreased. These anglers indicated that they had fished for an average of 22 years with 60% catching one or more *L. amia* a year. While it is acknowledged that these results are outdated and based on a small sample size, one can infer that perceptions are unlikely to have changed in light of the decreasing catches monitored since 2001. With 75% of respondents, that target *L. amia* in KZN, perceiving the stock to have decreased, this further confirms the need for stock rebuilding. This is of particular importance as even though this was not the perception in the Cape, *L. amia* are only seasonally abundant in KZN (winter months) and comprise mainly of migrating spawning fish.

The low *SBPR* further reveals that the current minimum size of 700 mm TL (587 mm FL), which was introduced in 1988, as well as the bag limit of five fish/angler/day (introduced in 1973), have proved inadequate to ensure sustainable use. A further decrease in the daily bag limit was implemented in April 2005 (two fish/angler/day), but because the results of the present study were based on exploitation rates from 2000-2006, the short period since the implementation of this new regulation meant that there was little chance for any effect on catches to have been detected. With the current legal size limit (587 mm FL that is equivalent to a t_c of 2 years), a large proportion of *L. amia* are caught without having had a chance to spawn. The length frequency histogram (Figure 5.1) shows that fish ranging from 587-800 mm FL make up a large proportion of fish tagged.

Stock management has generally been based on optimising yield while preventing growth overfishing, and hence reference points have previously been based on yield, i.e. F_{MSY} and $F_{0.1}$ (Griffiths *et al*., 1999). However, Table 5.3 illustrates the failure of the F_{MSY} management strategy, for at a t_c of 2 and 3 years, F_{MSY} is very similar to F_{SB25}. Thus, if F_{MSY} was used as a biological reference point for *L. amia* with age-at-first-capture equivalent to 2 or 3 years, taking into account instability of stocks due to natural variation, according to Gulland and Boerema (1973) there would be a good chance of stock collapse. The $F_{0.1}$ approach would be a better target reference point for *L. amia* as it is far closer to F_{SB40}. However, considering the current status of the *L. amia* stock (<25% $SBPR_{F=0}$) management considerations should focus on stock rebuilding rather than optimising yield.

A skewed sex-ratio can be used as a stock status indicator, such as in the LMP which suggests that management action is warranted when a sex-ratio is skewed by more than 10:1 (Griffiths *et al*., 1999). However, this is more applicable to hermaphroditic fish species, which generally exhibit changes in sex with size. Thus, in the same way as a decrease in average fish size in a population may reflect a decrease in abundance of adults (Maunder *et al*., 2006), a highly skewed sex-ratio may also indicate a decrease in abundance of the larger sex. Potts *et al*. (2008) found a sex-ratio of 1M:1.9F in the lightly fished stocks in southern Angola, and attributed this to males having a higher mortality rate and lower longevity than females, which become more dominant with increasing fish size and possibly out-compete smaller males for available food. Claereboudt *et al*. (2004) showed that female *Scomberomorus commerson* (king mackerel) were generally more prone to capture than males when using baited hooks. Claereboudt *et al*. (2004) attributed this to females requiring more energy to produce eggs. A sex-ratio skewed in favour of female *S. commerson* found by Govender (1995b) in KZN appears to support this hypothesis (Govender *et al*., 2006). As the *L. amia* fishery off the South African coast is primarily a hook and line fishery, there may be differing *F* values for male and female *L. amia*. High fishing effort in South African waters is expected to decrease the number of large *L. amia* in a population and consequently the proportion of female *L. amia* (Potts *et al*., 2008). With a sex-ratio of 1M:1F found in the study by van der Elst *et al*. (1993) (which was conducted over fifteen years ago using samples from as far back as 1978) it is possible that the effects of overfishing were already evident in the *L. amia* population before 1993.

Future research should thus consider separate per-recruit analyses for male and female *L. amia* from actual length-frequency data of *L. amia* caught by anglers along the entire South African coast. Length-frequency data would provide the age-frequency distribution of the catch, which could then be used in constructing a catch curve. With a possibility of different *M* and *F* values for males and females, separate per-recruit analyses should be carried out for the different sexes, as the *SBPR* would differ as a result (Govender *et al*., 2006). Management options could then be geared appropriately, e.g. implementing a minimum legal size limit that favours females, which mature at a larger size to males (van der Elst *et al*., 1993), ensuring larger fish are present in the *L. amia* population.

Based on the results in this chapter, as well as the results from the rest of this study, improved options for the management of *L. amia* need to be explored. Management options may come at a price with an associated decrease in yield, however, as a recreational trophy fish, van der Elst *et al*. (1993) recommended that *L. amia* should be managed to attain large size rather than high yield. The following chapter aims at doing just that.

CHAPTER 6

Conclusion and Management Considerations

The general decline in abundance of many South African linefish species is well documented (van der Elst and Adkin, 1988; van der Elst, 1989; Attwood and Farquhar, 1999; Penney *et al*., 1999; Fennessy, 2000; Griffiths, 2000; Mann, 2000; Pradervand, 2007). In particular, a number of recreationally important migratory linefish species have been shown, using per-recruit analyses, to be mainly over-exploited (i.e. *Argyrosomus thorpei*, Fennessy, 1994a; *Scomberomorus commerson*, Govender, 1995b; *Pomatomus saltatrix*, Govender, 1997) or collapsed (i.e. *Argyrosomus japonicus*, Griffiths, 1997a; *Argyrosomus inodorus*, Griffiths, 1997b; *Atractoscion aequidens*, Hutton *et al*., 2001; *Polysteganus undulosus*, Mann, 2007) (Figure 6.1). Very few similar species are optimally exploited (i.e. *Scomberomorus plurilineatus*, Chale-Matsau, 1996) or under-exploited (i.e. *Sarpa salpa*, van der Walt and Govender, 1996) (Figure 6.1). Based on the results of this study, the abundance of the *Lichia amia* stock has certainly declined.

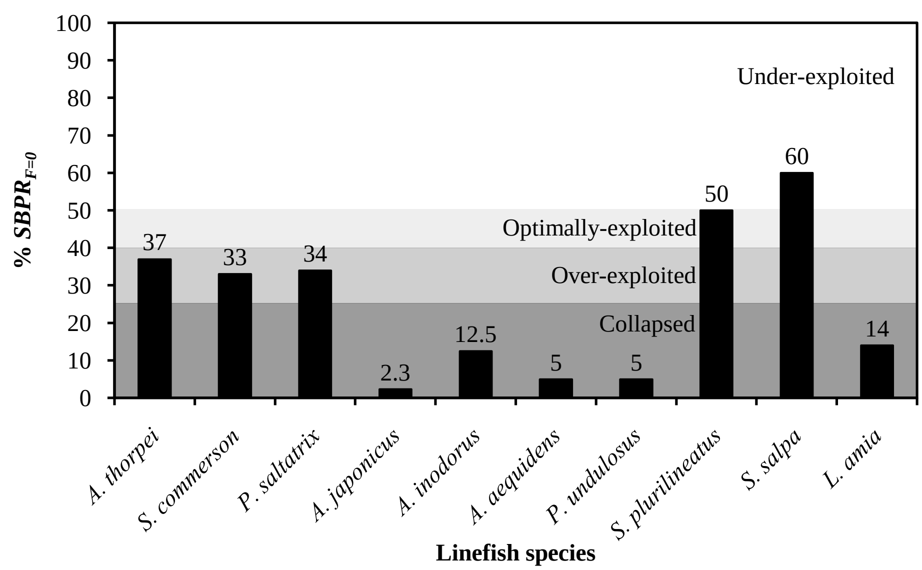


Figure 6.1: Levels of spawner-biomass-per-recruit (percent $SBPR_{F=0}$) for recreationally important migratory linefish species off the South African coast, including that found in this study for *Lichia amia*. Species arranged in the order in which they appear in the text above.

In the South African linefishery, management regulations have been implemented with the objective of regulating fishing mortality (*F*) by means of effort and catch controls such that fish stocks are maintained at the target reference point (i.e. 40% $SBPR_{F=0}$). Management regulations include minimum size limits, closed seasons, Marine Protected Areas (MPAs), daily bag limits (DBLs), decommercialization, gear restrictions, a moratorium on capture and effort control of the commercial fishery i.e. limited number of vessels (Griffiths *et al*., 1999). The Linefish Management Protocol (LMP) classifies linefish stocks into four management categories based on biological reference points (Chapter 5). This allows general action plans to be implemented for fish stocks falling into each category. The action plans for each category are as follows: (i) for under-exploited stocks (>50% $SBPR_{F=0}$) fishing effort could increase slowly to a level which maintains the stock at the target reference point; (ii) for optimally-exploited stocks (40-50% $SBPR_{F=0}$) management measures should remain unaltered; (iii) for over-exploited stocks (25-40% $SBPR_{F=0}$) management regulations should reduce the fishing effort so as to rebuild the stock to the target reference point; (iv) for collapsed stocks (<25% $SBPR_{F=0}$) the complete or partial closure of a fishery is necessary to enable stock recovery (Griffiths *et al*., 1999).

The per-recruit analysis undertaken in this study (Chapter 5) suggests that the *L. amia* stock has collapsed as the $SBPR_{current}$ <25% $SBPR_{F=0}$. Thus, according to the LMP complete or partial closure of the fishery is necessary. However, the rapid growth rate and relatively early attainment of sexual maturity means that small increases in age-at-first-capture are likely to result in sharp increases in the *SBPR* (Figure 5.4 and Table 5.3). These are life history parameters that are advantageous in rebuilding the *L. amia* stock and counteracting the high fishing pressure on *L. amia* (van der Elst *et al*., 1993). Furthermore, the fact that the stock assessment was based on fish that were tagged and released (Chapter 5), and not actually killed, further reduces the risk. The recent implementation (April 2005) of a reduced daily bag limit from five to two fish/angler/day may also have the desired effect of reducing catch and contributing to stock rebuilding (the effectiveness of which is discussed below). Nevertheless, any one of the following management scenarios would result in an increase in *SBPR* of *L. amia* above the 25% $SBPR_{F=0}$ threshold, and although yield may not be optimised (Chapter 5), they would more importantly contribute to the rebuilding of the *L. amia* stock without closing the fishery:

1. Retain the current size limit (587 mm FL) and reduce the *F* by 33% to 0.281 from 0.421 year^{-1}, i.e. $F_{current}$ (method of reducing *F* is discussed below),
2. Increase the minimum size limit to 667 mm FL (t_c = 3) and reduce *F* by 14% to 0.363 year^{-1},

3. Increase the minimum size limit to 763 mm FL (t_c = 4),
4. Increase the minimum size limit to 842 mm FL (t_c = 5).

To assess which of these possible management scenarios would be the most effective, the percent increase in *SBPR* was plotted as a function of age in years (Figure 6.2). When plotting the increases in *SBPR* under the different management scenarios (1 to 4), scenario 1 and 2 will only increase the *SBPR* to 25% $SBPR_{F=0}$ after ten years (Figure 6.2). Scenario 3 would increase the *SBPR* at a faster rate with 25% $SBPR_{F=0}$ reached after about six years. What is also evident is that, in addition to reaching 25% $SBPR_{F=0}$ in just 4 years, scenario 4 is the only scenario in which the target reference point (40% $SBPR_{F=0}$) would be reached over the life span of *L. amia*. However, setting a minimum size limit at 842 mm FL (scenario 4) would exclude 96% of the current catch of *L. amia* and would thus effectively be equivalent to closing the fishery. Scenario 3 would probably be the most suitable, because of the difficulty in enforcing methods that reduce fishing effort (as required for scenarios 1 and 2) and at a t_c = 4, which is close to 50% maturity, immature fish and many first spawning individuals would be protected. Increasing the minimum size is also in line with managing the species as a "trophy fishery" in that only the largest individuals caught would be kept, as recommended by van der Elst *et al*. (1993). In addition, the exponential relationship between fish size and fecundity found for *Caranx melampygus* (Sudekum *et al*., 1991), a similar size carangid to *L. amia*, suggests that even relatively small changes in the mean adult size could result in a considerable change in the *L. amia* population fecundity (Potts *et al*., 2008). By increasing the minimum size limit to 763 mm FL from 587 mm FL, the mean adult size of the *L. amia* population should increase thus contributing to an increase in the population fecundity (Murua *et al*., 2003).

Management of South African Linefish has given little attention to maximum size limits. If implemented correctly, a maximum size limit would ensure larger fish are protected. The protection of larger fish, in heavily exploited populations, is important as large old fish are harvested more rapidly because they are exposed to size-selective fishing mortality (Trippel, 1999). Generally larger fish have a higher reproductive potential as, for example, larger females produce exponentially more eggs and the eggs they produce are larger and more viable than those produced by smaller females, i.e. the BOFFF (Big Old Fat Fecund Female Fish) Hypothesis (Longhurst, 2002; Berkeley *et al*., 2004; Walsh *et al*, 2006; MPA News, 2007). Once removed from a population, the population fecundity declines because of the reduced abundance of spawners, especially when there is a reduction in large, highly fecund females (Murua *et al*., 2003). High fishing effort in South African waters is expected to decrease the number of large *L. amia* in a population and consequently the proportion of female *L. amia* (which become more dominant with increasing fish size as males have a higher mortality rate and lower longevity than females) (Potts *et al*., 2008). A maximum size limit would thus be appropriate for the South African *L. amia* fishery and assist in stock rebuilding. By running the per-recruit models in Chapter 5 with only those *L. amia* between the ages of 3 and 5 selected, the effect of a maximum size limit in conjunction with a minimum size limit, on the current level of *SBPR* was simulated (i.e. a slot limit). At the current fishing mortality (0.421 year^{-1}) and at a t_m of four years (age at 50% maturity), a minimum t_c of three years (667 mm FL) and a "maximum t_c" of five years (842 mm FL), the $SBPR_{F=0}$ would be increased to 31%. This result was similar to that observed when running the per-recruit models with the same input values and a t_c of four years, but resulted in the lowest yield out of the different t_c values used when running the models (Chapter 5). Importantly, an assessment of the reproductive strategy and fecundity of *L. amia* is needed to adequately select a maximum size limit that ensures that the fecundity of the population is increased. However, without acceptance by the fishing public and adequate enforcement, the benefits of a maximum size limit would not be achieved.

Although the first three scenarios do not reach the target reference point, the long-term management goal would be to maintain the *L. amia* stock at 40% $SBPR_{F=0}$ after initial stock rebuilding. Mace and Sissenwine (1993) stressed the large risk associated with low levels of *SBPR* and Punt (1993) showed that even when managed at F_{SB35} spawner biomass could still drop to <20% $SBPR_{F=0}$. For this reason, it is essential for the *L. amia* stock to be reassessed at least five years (half the maximum age of this species) after the implementation of any new management regulations to assess their effectiveness.

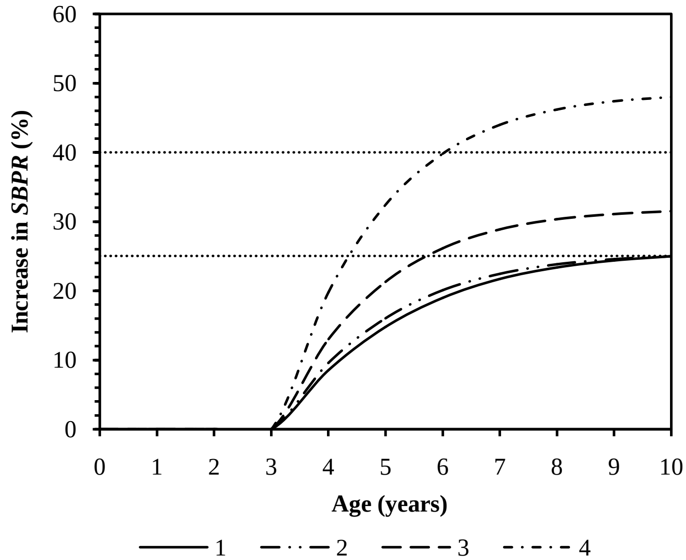


Figure 6.2: Rate of increase (%) in relative *SBPR* after the implementation of management scenarios 1 to 4. (The assumption of knife-edge maturity means the *SBPR* increases after age three).

If scenario 3 is not deemed acceptable and scenario 1 or 2 is preferred, the required reduction in *F* can be achieved through daily bag limits. The effectiveness of daily bag limits in reducing the fishing mortality of *L. amia* was assessed through analysis of daily catches of anglers targeting gamefish (*L. amia* and other carangids) in KZN and those actively targeting *L. amia* in the Transkei. For this purpose, raw data from a roving creel census conducted in KZN (1994-1995) (Brouwer *et al*., 1997) and one conducted in the former Transkei during 1997 (Mann *et al*., 2003) were obtained. During this time, the daily bag limit for *L. amia* was five fish/angler/day. In KZN, out of 89 anglers inspected who were targeting gamefish, only nine *L. amia* were caught by eight different anglers (one of the anglers had caught two fish). In the Transkei, 16 anglers inspected had actively targeted *L. amia* with only two fish caught (two anglers caught one fish each). The potential reduction in catch associated with a particular daily bag limit was determined by the fraction of the surveyed catch that the daily bag limit would have prevented (Attwood and Bennett, 1995). The daily bag frequencies for *L. amia* caught in KZN and in Transkei, and the potential percent decrease in *F* resulting from the enforcement of various daily bag limits are given in Table 6.1. It is evident that the daily bag limit of five fish/angler/day was ineffective in reducing fishing mortality of *L. amia* in both KZN and Transkei. According to the available data, the reduction of the bag limit to two fish/angler/day implemented in 2005 will also have little effect on reducing fishing mortality in these regions. If the fishery for *L. amia* was not closed, a bag limit of one fish/angler/day would thus be the most appropriate in reducing the fishing mortality of *L. amia*, but would not reduce it to the extent that is required for scenarios 1 or 2. The effectiveness of this method can however not be accurately assessed given the paucity of data. In reality the potential decrease in *F* may be greater than that calculated and, with the recent decrease in the overall fishing effort in KZN (Mann *et al*., 2008), and in fishing mortality from 1984-2006 shown in Chapter 3 (Figure 3.11 and 3.13), the current DBL may in fact be sufficient. Furthermore, based on anecdotal information, large catches of *L. amia* are periodically made at certain locations (e.g. Port St Johns, Kingsburgh, Tongaat River mouth, Tugela River mouth etc) and the reduced bag limit will reduce fishing mortality in these circumstances if it can effectively enforced. An extensive creel survey along the entire South African coast is needed in future research for the effectiveness of a reduced bag limit to be determined.

Table 6.1: Observed bag frequencies (Freq.) and potential percentage decrease in fishing mortality (%*F*) as a result of various daily bag limits (DBLs) along the KwaZulu-Natal and Transkei coasts.

DBL	**KZN**		**Transkei**	
	Freq.	**%*F***	**Freq.**	**%*F***
0	81	100	14	100
1	7	11	2	0
2	1	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
No. *L. amia*	**9**		**2**	
No. anglers	**89**		**16**	

Inadequate enforcement of management regulations and illegal fishing are a major concern in South Africa's linefishery (Cockcroft *et al*., 1999; Griffiths *et al*., 1999; Mann *et al*., 2002b). In addition, because past management regulations have largely proved inadequate (this study, Attwood and Bennett, 1995; Griffiths, 1997), a broader approach to management is required to ensure the sustainable catch of *L. amia*. An ecosystem approach would ensure a holistic approach to management (Hoggarth *et al*., 2006) and would complement the management options already mentioned. This type of approach to management considers all significant interactions between species and the wider environment (FAO, 2003; Hoggarth *et al*., 2006). Such an approach is particularly applicable to juvenile *L. amia* <500 mm FL. *L. amia* this size and smaller exhibit resident behaviour in Cape estuaries and good management practices in these ecosystems will increase the rate of juvenile survival. However, estuaries are under threat from increased development in catchment areas, reduced freshwater inflow and increased use of estuarine resources (Lamberth and Turpie, 2003). This has resulted in the reduction and degradation of habitat availability for juvenile *L. amia* and has thus affected the survival of fish in estuaries (Whitfield, 1997). Furthermore, juvenile *L. amia* confined to estuaries are highly accessible to anglers and are exposed to high levels of fishing effort. Although most of these are under the legal size limit (587 mm FL), they are targeted by anglers mainly with the intention of catch and release (Chapter 3). However, recent work on mortality rates of released fish suggests that relatively high proportions of released fish do not survive (Bartholomew and Bohnsack, 2005). The maintenance, conservation and even rehabilitation of estuarine environments and catchment areas in the Cape that serve as primary nursery areas during the early life-history stages are therefore integral to the wise management of *L. amia*. The management of estuarine ecosystems will not only benefit *L. amia*, but other important estuarine dependent linefish species (e.g. *Argyrosomus japonicas* and *Lithognathus lithognathus*). The C.A.P.E. estuaries programme has been established with similar objectives in mind (i.e. improving estuary management and developing management plans for estuaries) (C.A.P.E., 2008). The establishment of estuarine protected areas (EPAs) may thus prove an effective management tool for these species. For such EPAs to be effective, further research would be required to determine the most suitable estuaries in addition to taking into account the far-reaching social impacts of restricting access to these areas. The recent incorporation of the Goukou estuary into the Still Bay MPA and the proposed incorporation of the Sundays River estuary into the Greater Addo Elephant Park MPA are positive developments in this regard.

As discussed above, an EPA would be applicable to resident juvenile *L. amia* in estuaries, but a MPA would probably be less effective at providing protection for the migrating portion of the *L. amia* stock unless greater knowledge could be obtained on the exact location of the spawning grounds off the KZN coast. If it could be shown that adult *L. amia* aggregate to spawn in defined geographical areas then establishment of no-take MPAs in these regions could benefit protection of the adult stock (as described for reef fish spawning aggregations by Colin *et al*., 2003). A closed season on the other hand would potentially offer greater protection for migrating *L. amia*, especially because closed seasons are better suited to regions with poor enforcement (Wilson *et al*., 1994;

Caddy, 1999). *L. amia* are abundant in KZN from April-November and when in KZN waters adults experience much higher levels of fishing effort than when in Cape waters (Chapter 3). During July/August, peak holiday season and the abundance of *Pomatomus saltatrix* (elf/shad) results in far higher angling effort (Chapter 2) and it would probably be unacceptable to many to close fishing for *L. amia* during this time. However, October and November would be more appropriate as these months fall out of the peak holiday season and it is during this period that *CPUE* of *L. amia* is highest along the KZN coast (Chapter 2). In addition, this period coincides with peak spawning of *L. amia* (van der Elst *et al*., 1993). October-November also coincides with the closed season for *P. saltatrix*, an important prey species of *L. amia*. Using *P. saltatrix* as live bait is a very successful and widely used method for capturing *L. amia* along the KZN coast. A closed season for *L. amia* coinciding with that of *P. saltatrix* would help reduce the illegal capture of *P. saltatrix* as live bait for *L. amia*. This would not only contribute to the effectiveness of the closed season in rebuilding the *P. saltatrix* stock, which is the most heavily exploited linefish species along the KZN coast making up >60% of the total catch (Pradervand, 2007), but would also assist in reducing the effort directed at *L. amia* and in doing so contribute to the rebuilding of the *L. amia* stock.

Potts *et al*. (2008) developed an ecosystems approach to management of *L. amia* in southern Angola in the form of a Traffic Light Precautionary Management Framework (TLPMF) based on baseline biological and ecological information. In order to be effective, this framework must incorporate multiple indicators, i.e. environmental integrity, life-history strategies, stock production and fishery characteristics (Caddy, 2002). The critical quantitative baseline indicators determined by Potts *et al*. (2008), from the relatively unfished *L. amia* fishery in southern Angola, allowed a Traffic Light System (TLS) to be used with three colours to quantify concern for the state of an indicator, namely: green (healthy), orange (warning) and red (danger). Although constructed for *L. amia* in southern Angola, if the results from this study were compared to the baseline reference points in the TLS developed by Potts *et al*. (2008), two red lights would be obtained. Two red lights are assigned because the current *CPUE* and total mortality determined in this study are ≤40% (Chapter 2) and ≥0.65 year^{-1} (0.752 year^{-1}) of the baseline reference points in Potts' *et al*. (2008) TLS respectively. Potts *et al*. (2008) calculated the cut-off value for *Z* (0.65 year^{-1}) from the total mortality determined by van der Elst *et al.* (1993) + 0.1 (i.e. 0.55 year^{-1} + 0.1). Unfortunately two other indicators proposed by Potts *et al*. (2008), the mean size of mature fish and the biomass of an important prey species of *L. amia* in South African waters, could not be determined. However, two red lights, no matter what the other two are, fall in the second and third tier of the TLS management framework (p 118, Potts *et al*., 2008). The second tier of the management framework indicates the need for closed areas (MPAs) and the third tier recommends fishery closure.

The results of this study emphasise the need for accurate life-history information and the periodic revision of management regulations as well as life-history parameters of South Africa's exploited linefish species. The management recommendations outlined in this study can only be made effective and realised in collaboration with relevant user groups and their success will depend on the degree of user compliance. In addition, without adequate implementation and enforcement, which has been poor in the past along the South African coast (Cockcroft *et al*., 1999; Griffiths *et al*., 1999; Mann *et al*., 2002b) the management options discussed, will be ineffective. Inadequate enforcement urgently needs to be improved through education and awareness programs, in addition to an increase in the number of enforcement officers, as recommended by Cockcroft *et al*. (1999).

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APPENDIX I

A: Diet of *Lichia amia* in Cape estuaries

	Coetzee, 1982, p 180				Smale and Kok, 1983, p 340												Marais, 1984, p 214				Bennett, 1989c, p 402		
	Swartvlei				Knysna						Swartvlei						Eastern Cape				Bot River	Kleinmond	Palmiet
	189-734 mm TL				49-99 mm FL			111 - 515 mm FL			40-97 mm FL			107-329 mm FL			155-632 mm SL				71-460 mm TL	95-495 mm TL	443-820 mm TL
Prey	% F	% C	% Dom	TL (mm)	% F	% N	% D	% F	% N	% D	% F	% N	% D	% F	% N	% D	% F	% N	% M	I.R.I	% V	% V	% V
Aquatic macrophytes	10.0	0.9	1.0	298-618																			
Filamentous algae	1.0	0.4	1.0	298																			
Crustacea																	2.6	19.8	0.9	54.0			
Anomura																	1.1	1.3	0.3	2.0			
Macrura																							
Caridea					30.3	25.3	30.9	9.4	8.7	2.8	11.8	10.5	12.5	8.3	3.4	2.7							
Macropetasma africanum																	0.5	2.1	0.4	2.0			
Palaemon pacificus	22.0	19.1	19.0	189-504																	0	1.0	0
Penaeus spp.	1.0	0.1	0	398																			
Unidentified					6.1	4.8	1.8	9.4	6.5	1.9													
Mysidacea																							
Mesopedopsis slabberi					3.0	19.3	0.5																
Rhopalophthalmus terranatalis																	1.1	16.4	0.2	18.0			
Mollusca																							
Gastropoda	1.0	<0.05	0	452																			
Osteichthyes																	97.9	80.2	99.1	17 553.0			
Argyrosomus hololepidotus																	0.5	0.1	1.3	1.0	5.0	8.0	0
Clinidae	3.0	2.8	3.0	329-398																	59.0	0	0
Clinus spatulatus																							
Diplodus sargus								3.1	1.1	6.9													
Engraulidae								3.1	2.2	8.8													
Etrumeus teres								6.3	3.3	3.3													
Gilchristella aestuarius	27.0	23.6	25.0	189-524				6.3	3.3	12.6	5.9	5.3	1.8	16.7	6.9	6.6	12.2	12.9	2.9	193.0			
Gobiidae	13.0	9.9	11.0	298-594	33.3	19.3	43.1	40.6	30.4	14.3	11.8	10.5	9.2	58.3	34.5	19.1	2.1	1.7	0.6	5.0			
Caffrogobius multifasciatus																							
Psammogobius knysnaensis																					0	1.0	0
Hemirhamphus								3.1	1.1	1.7											5.0	6.0	0
Hyporhamphus capensis	1.0	0.1	0	565																			
Hepsetia breviceps	13.0	4.9	5.0	205-525	3.0	2.4	1.0	28.1	16.3	8.8	17.6	21.1	58.0	33.3	44.8	63.1	1.1	2.0	0.9	3.0			
Heterosomata	1.0	0.3	0	521																			
Lichia amia																	1.1	0.4	1.8	3.0			
Lithognathus lithognathus	1.0	0.7	1.0	326																			
Micropterus salmoides																	21.3	21.5	23.4	956.0			
Monodactylus falciformis	9.0	7.4	7.0	446-734										8.3	6.9	2.7					0	22.0	0
Mugilidae					30.3	16.9	16.1	25.0	10.9	13.2	5.9	5.3	3.2				9.0	3.1	12.3	139.0			
Liza dumerili																	0.5	0.1	0.4	0.3	26.0	60.0	0
Liza richardsoni	8.0	7.9	8.0	227-594													4.8	1.3	8.0	45.0			
Mugil cephalus																	4.8	1.3	10.2	55.0			
Oreochromis spp.																	1.1	0.9	1.1	2.0			
Pomadasys commersonni																	1.1	0.3	2.6	3.0			
Pomadasys olivaceum																	2.1	2.8	4.3	15.0	5.0	0	0
Rhabdosargus holubi	9.0	8.2	9.0	320-621													2.7	0.9	2.4	9.0			
Sarpa salpa								6.3	5.4	10.7													
Spondyliosoma emarginatum								3.1	4.3	12.0													
Unidentified fish	21.0	14.2	13.0	237-630	21.2	12.0	6.6	15.6	6.5	3.1	47.1	47.4	15.2	8.3	3.4	5.7	39.4	30.5	26.7	2 254.0			
n			150			33			32			17			12			188			3	12	39

B: Diet of *Lichia amia* in KZN estuaries

	Whitfield and Blaber, 1978, p 677 St Lucia 120-782 mm TL			Blaber and Cyrus, 1983, p 183 KZN estuaries 95-545 mm SL		
Prey	**% F**	**% N**	**% W**	**% F**	**% E**	**Prey SL (mm)**
Crustacea						
Penaeidae				5.0		
Osteichthyes						
Gilchristella aestuarius	9.0	5.0	0.1	5.0	0.5	30
Hilsa kelee				15.0	8.0	50-90
Hyporhamphus capensis				5.0	0.3	50
Mugilidae	45.5	25.0	43.1			
Mugil cephalus				10.0	5.0	70-120
Valamugil cunnesius				20.0	20.0	100-150
Pomadasys commersonni	9.0	5.0	12.4			
Rhabdosargus holubi	9.0	5.0	12.0			
Rhabdosargus sarba	45.5	25.0	28.1			
Sarotherodon mossambicus				5.0	40.0	170
Thryssa vitrirostris	18.1	20.0	1.3	10.0	25.0	70-160
Unidentified fish	18.0	15.0				
n		**11**			**27**	

C: Diet of *Lichia amia* in the Eastern Cape surf-zone

	Smale, 1983, p 18								
	401-700 mm FL			701-1 200 mm FL			401-1 200 mm FL		
Prey	**% F**	**% N**	**% m**	**% F**	**% N**	**% m**	**% F**	**% N**	**% m**
Crustacea									
Macropetasma africana	3.6	3.3	0.1				1.3	1.8	<0.1
Mollusca									
Sepiidae				2.1	1.0	4.7	1.3	0.5	3.6
Osteichthyes									
Argyrosomus hololepidotus	3.6	1.7	0.1	2.1	1	3.2	2.7	1.4	2.5
Umbrina canariensis	3.6	0.8	0.1				1.3	0.5	<0.1
Engraulidae				4.3	2	0.1	2.7	0.9	<0.1
Engraulis capensis	39.3	51.2	24.3	25.5	18.2	5.2	30.7	36.4	9.8
Etrumeus teres	7.1	2.5	5.7	8.5	5.1	2	8	3.6	2.9
Sardinops ocellata	7.1	2.5	4.3	36.2	35.4	39.2	25.3	17.3	31
Liza richardsoni	3.6	0.8	1	4.3	2	2.6	4	1.4	2.2
Myxus capensis				2.1	1	4.1	1.3	0.5	3.1
Pomadasys olivaceum	10.7	3.3	0.7				4	1.8	0.2
Pomatomus saltatrix				2.1	2	0.8	1.3	0.9	0.6
Scomber japonicus	10.7	3.3	11.4	10.6	8.1	17	10.7	5.5	15.7
Sparidae	3.6	0.8	0.1				1.3	0.5	<0.1
Cheimerius nufar	10.7	3.3	7.4				4	1.8	1.8
Pagellus natalensis	14.3	5.8	10.6	17	14.1	17	16	9.5	15.5
Sphyraenidae	3.6	0.8	0				1.3	0.5	0.1
Trachurus trachurus	17.9	14.9	32.3	4.3	7.1	3.9	9.3	11.4	10.6
Unidentified fish	21.4	5	1.4	6.4	3	0.2	12	4.1	0.5
n		**28**			**47**			**75**	

KEY: %F = Percent frequency; **%N** = numerical frequency; **%E** = percent of energy intake; **%C** = composition; **%V** = volume, **%Dom** = dominance; **%M** = percentage of body mass; **% m** = wet mass; **%D** = dry mass; **%W** = gravimetric analysis (weight); **IRI** = Index of Relative Importance; ***n*** = number of stomachs analysed

APPENDIX II

ANGLER OPINION SURVEY

Following the last SAMLMA meeting on 2 May 2001, representatives of the various recereational linefish sectors were requested to gather comment on the status of garrick/leervis from their members. Your time in completing this short questionnaire will be greatly appreciated.

Oceanographic Research Institute (ORI)

- WHICH IS YOUR PRIMARY AREA OF FISHING?

  Tick one: ☐ KZN ☐ Transkei ☐ E. Cape ☐ S. Cape ☐ W. Cape

- WHICH IS YOU MAIN TYPE OF FISHING?

  Tick one: ☐ Shore ☐ Estuary ☐ Skiboat ☐ Spear

- HOW MANY YEARS HAVE YOU BEEN FISHING? ☐ Years

- CONCERNING GARRICK/LEERVIS

  Do you target this species? Yes ☐ No ☐

  How often do you catch garrick?

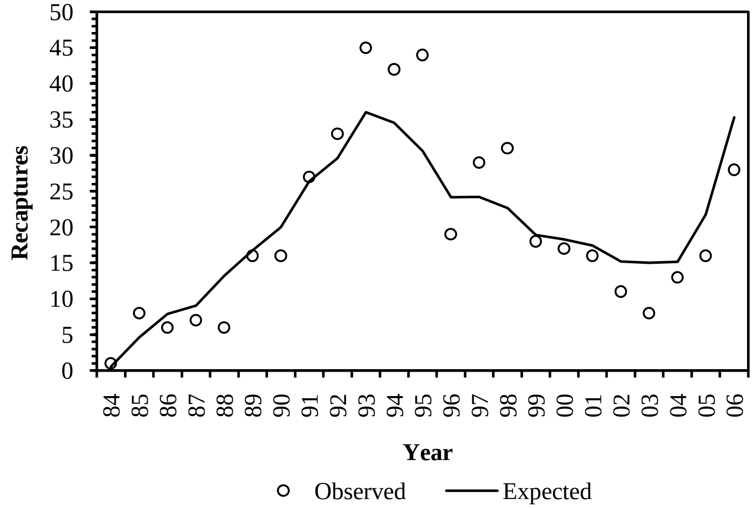
  Seldom ☐ Once or twice a year ☐ More thank twice a year ☐

  Based on your own experience, do you think garrick has increased or decreased over the last 10 years?

  Increased ☐ Decreased ☐ No change ☐

HOME TOWN ………………………………… DATE ………..……..………..………..

APPENDIX III



A: Observed and expected recaptures of *Lichia amia* tagged along the South African cost (1984-2006)

B: Observed and expected recaptures of tagged *Lichia amia* along the South African coast (1984-2006) and associated deviance values

Year	Observed	Expected	Deviance
84	1	0.51	0.29
85	8	4.63	1.68
86	6	7.89	0.54
87	7	9.01	0.53
88	6	13.18	6.38
89	16	16.74	0.03
90	16	19.95	0.90
91	27	26.39	0.01
92	33	29.59	0.36
93	45	36.02	1.92
94	42	34.53	1.42
95	44	30.60	4.57
96	19	24.16	1.29
97	29	24.20	0.84
98	31	22.65	2.48
99	18	18.90	0.04
00	17	18.25	0.09
01	16	17.41	0.12
02	11	15.18	1.42
03	8	15.02	4.88
04	13	15.14	0.33
05	16	21.76	1.86
06	28	35.30	1.75