Distribution, abundance and population dynamics of beachworms (Onuphidae) in Queensland/N.S.W. and the impact of commercial and recreational fishing

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Objectives

1. To determine where and why beachworms are located on QLD/N.S.W. surf beaches;
2. To determine how the various onuphid species that make up the beachworm fishery are distributed relative to each other and in time;
3. To determine if levels of commercial and recreational fishing effort relate to the yield and sustainability of the fishery;
4. To make recommendations for management of the fishery based on an evaluation of catch and effort data and research of the biology of the worms.

Non Technical Summary:

To date, very little research has been done on Australian beachworms (Family: Onuphidae), yet recreational fishing is a very popular activity in Australia and a variety of invertebrates, including beachworms, is used for bait. Exploitation of these animals for use as bait may remove considerable numbers of beachworms, especially from the accessible intertidal zone. A semi-regulated professional fishery exists for beachworms in Queensland and New South Wales. However, so far only the New South Wales fishery has been described, so the research reported here was done in order to describe the nature of the fishery for beachworms in Queensland. The primary objectives of the study were (1) to describe the distribution and abundance of beachworms in Queensland and NSW, (2) to describe which of the different species of beachworms are found on different beaches and how this variation relates to the commercial beachworm fishery, (3) to determine if the commercial and recreational fishery are sustainable and (4) to provide information for the future management of the fishery. Two distinct approaches were used in this study. The first one included creel surveys (2000 and 2001) of recreational fishers at a beach fishing competition on Fraser Island, Queensland and the analysis of commercial beachworm fisheries data, obtained from the Queensland Fishery Service. The second approach, involved sampling of a sandy beach in Queensland, over a period of approximately 18 months, to obtain information on the patterns of abundance of beachworms in space and time. None of the core objectives of the study, as defined above, were achieved, although the report does include information describing the magnitude of the commercial catch in Queensland, plus limited information on the nature of the recreational fishery associated with a commercialised fishing competition on Fraser Island.

Recreational fisheries generally caught and used only small numbers of worms (less than 10 worms a day) so this sector may not pose and threat to the long-term sustainability of the fishery. Catch per unit effort in the Queensland commercial fishery was three times greater than that in the New South Wales beachworm fishery, suggesting more information is required on whether these levels of harvesting are sustainable. Analysis of the commercial fisheries data suggested that the abundance of beachworms varied seasonally, with more animals available in summer than winter, but this was the opposite trend shown in the data obtained from the limited sampling done on a single beach.

KEYWORDS: **beachworms surf beaches, bait harvesting, recreational fishery, commercial fishery**

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Background

Beachworms (*Australonuphis* spp.) are the basis of a modest fishery in both Queensland (1996 catch = 578,000 worms @ $1.00 per unit) and N.S.W. (1995/96 catch = approximately 563,000 worms @ $1.00 per unit). The total value of the fishery in both states was therefore about $1.14 million in 1996. In both regions, an unknown but probably substantial recreational fishery also exists. Most, if not all, of the beachworm catch is used as bait by recreational fishers either as freshly caught and live or preserved and frozen worms. Very little is known of the biology/ecology of Australian beachworms. In fact, only three major scientific papers, all by Paxton (1979, 1986, 1996) and mostly taxonomic in content, have been published. Consequently, the knowledge upon which the fishery in both states is managed is at best anecdotal.

Need

1. Demand for baitworms presently exceeds supply.

2. The number of worm gathering licenses is currently frozen. However, potential wormers can set themselves up to earn an apparently good income with only a relatively small capital investment. In combination, these two facts will probably lead to substantial future pressure for allocation of new worm gathering licenses. Without any real knowledge of what might be a sustainable harvest, such allocations should be resisted.

3. No estimates of the recreational beachworm fishery have been made. Anecdotal evidence indicates that this fishery is very substantial and is largely unregulated. No good management protocols can be set in place unless valid estimates of professional and recreational fishing effort have been made and related to the worm populations and their ability to sustain harvesting.

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Chapter 1: General Introduction

Sandy beaches account for 47 % of the Australian coastline (Fairweather, 1990), and 70 % of coastlines worldwide (Dugan and McLachlan, 1999). These high-energy environments are an important interface between the earth's oceanic and terrestrial ecosystems. At this interface, a large number of different biological and physical processes occur, the most important being nutrient and water cycling (both within and between the oceanic and terrestrial systems) and the dissipation of energy between the two systems (Fairweather and Quinn, 1994). It is this energy dissipation in the form of waves and tides that results in the formation of sandy beaches. In addition, both on-shore and long-shore movement of water and sediment continually work to move the beach substrata, creating a highly mobile and fluid environment (McLachlan and Turner, 1994).

Sandy beaches are structurally simple with only sand and waves essential for their creation (McLachlan and Turner, 1994). They extend from the upper-shore dunes to the sand beyond the breakers (McLachlan and Erasmus, 1983). This broad-scale structural simplicity does not reflect the true nature of sandy beach systems, which are highly complex and dynamic, controlled by both physical and biological processes (McLachlan, 1983). The systems are highly fluid in nature (McLachlan, 1988) and hence provide far less structure and stability than a rocky shoreline. This produces a highly dynamic environment, dominated by interactions among physical components of the system, such as wave height and period, sand grain size, beach slope, tidal range and the beach type (Masselink and Short, 1993; Short, 1996). To date, research has predominantly focused on the effects of these physical variables on beach faunal communities.

1.1. Classification of beaches

Beaches have traditionally been classified by their degree of exposure or wave activity into one of two categories, either exposed, high energy beaches, or sheltered, low energy beaches. This classification was recognised as being too broad to be of any practical use so McLachlan (1980) introduced a simple rating system based on the extent that hydrodynamic forces acted on the intertidal zone. This system was based on information on wave action, sand particle size, beach slope and presence of macrofaunal burrows, that together gave a beach a rating on a 20 point scale. A score of 1-5 referred to very sheltered beaches with virtually no wave action and abundant macrofaunal burrows. At the other end of the scale, a score of 16-20 referred to exposed beaches with high wave action. These exposed beach habitats are amongst the harshest aquatic ecosystems on earth (McLachlan *et al.*, 1993) and are usually occupied by more resilient motile macrofauna, well adapted for living in a physically challenging environment (McLachlan, 1980). Unfortunately, this classification scheme tends to be somewhat subjective and difficult to standardise across different systems and observers. More recently, the physical features of the beaches of the East Coast of Australia were described using a more rigorous classification system, based on the concept of beach morphodynamic state (Short and Wright, 1983; Wright and Short, 1984).

1.2. Morphodynamic State

Morphodynamic state describes both the hydrodynamic condition and depositional form of sandy beaches (Short and Wright, 1983). This classification scheme uses a dimensionless index based on sediment fall velocity, wave height and wave period (Dean's parameter) that expresses the dynamic interaction between the wave regime and the sediments found on the beach (Short and Wright, 1983). Six commonly observed beach states have been defined and these fall within three broader categories: dissipative, intermediate, and reflective. Dissipative beaches (Dean' parameter > 6) have fine-grained sands and high wave activity (waves > 2 m). Morphologically, dissipative beaches have a gently sloping beach face, with a broad surf zone with sandbars. These are high energy beaches, defined by the energy of the surf zone and are the least physically demanding type of sandy beach for fauna. At the opposite end of the spectrum, the reflective beach (Dean' parameter < 1), has course-grained sands and low wave activity (waves < 0.5 m). Reflective beaches have a steeply sloping face and the waves do not break in rows, but instead break on the beach face and surge up the beach. These are low energy beaches, defined by the low energy of the surf/breaking zone (Short, 1996). Between these two extremes, there are four intermediate beach states, the longshore bar-trough, rhythmic bar and beach, transverse bar and rip, and low tide terrace (Short, 1996). These beach states have increased sediment exchange rates and can move from one intermediate state to another as conditions change (Short and Wright, 1983).

Although research has been done linking variation in measures of physical conditions to the distribution of biota on sandy beaches, most studies have focused primarily on comparing beaches of different morphological state, using a snap-shot (single sampling event) sampling design (Brazeiro and Defo, 1996). While providing some basic information on the abundance and range of fauna that occur on the beach at that point in time, such approaches do not provide any information on temporal variation of the biota. Moreover, many of these studies also lack appropriate measures of spatial variation to allow robust comparisons to be made among individual sites or beaches (e.g. Lee, 1996; Defo and Brazeiro, 1997). Any understanding of the dynamics of the macrofaunal communities living on sandy beaches requires data incorporating appropriate measures of spatial and temporal variation in the physical and biological features of the beach (James and Fairweather, 1996)

1.3. Ecology of Sandy Beach Fauna

1.3.1. Role of Physical Factors

As in other physically harsh environments, intertidal macrofaunal communities on sandy shores tend to be species-poor. The overall abundance and biomass of those species that are present may, however, be relatively large, but this if often attributable to a single or few species that are adapted to local environmental conditions. In a review of zonation on sandy beaches, McLachlan and Jaramillo (1995) challenged the role of biological factors in structuring beach macrofaunal communities. They argued that because sandy beaches are dynamic and mobile, the animals are well adapted to a highly mobile lifestyle, with individuals and community structure changing in response to the changing physical environment. This view has been supported by a number of studies in which the composition of the macrofaunal communities on beaches was correlated with the specific beach morphodynamic state (Fleischack and Freitas, 1989; Hacking, 1998; Siemens *et al*., 2001). It has also been shown that species richness, abundance and biomass of the macroinfauna increase from reflective to dissipative beaches (Jaramillo and McLachlan, 1993; Jaramillo *et al*., 1998).

Living within the intertidal zone of a sandy beach requires that animals be able to escape from wave action, most often done through rapid burrowing. Different taxa have different capacities to burrow into these sediments. The sand crab *Emerita sp.* is a sediment generalist, able to burrow at similar rates in sediments of different sizes (Dugan *et. al*., 2000; Jaramillo *et. al.,* 2000). In contrast, burial time in donacid bivalves is correlated with the grain sizes in the substratum and the size of the individuals, with smaller individuals being able to bury themselves the fastest and fine sediments being the easiest to bury into (Nel *et. al.*, 2001).

Beach macrofauna tend to remain buried beneath the sediment during low tide but most show a high degree of mobility, undertaking tidal migrations to remain within the different zones on the beach. *Donax serra* is an exception to this general rule, instead exhibiting semi-lunar movement up and down shore on spring-neap tidal cycles (Dugan and McLachlan, 1999). Macrofauna also show a great deal of variability in spatial distribution not only due to their migrations up and down to face of the beach, but also they are also patchy at a number of different scales. This patchiness has been shown to be linked to longshore movement of animals along the coast, as they mature and become displaced by longshore currents. Aggregations of donacid bivalves have been correlated with the formation of longshore cusps and bays on reflective beaches (Dugan and McLachlan, 1999) but no such relationship appears to exist on dissipative beaches, probably as a result of the less well defined cusp-bay formation exhibited on such beaches (James, 1999). Mole crabs *Emerita sp.* have been shown to aggregate in the region of longshore cusps on an intermediate-dissipative beach (Gimenez and Yannicelli, 2000). However, in contrast, Defeo *et al.* (2001) and Contreras *et al*. (2003) found no significant differences in the abundance of *Emerita sp*. or other crustaceans, between dissipative and reflective beaches, suggesting that morphodynamic state alone does not control the abundance of these animals at this larger scale.

Some studies have attempted to define zones based on the presence of specific organisms, or a functional group, at particular heights on the shore. For example, the high tide zone of sandy beaches has been characterised by the presence of isopods (Glynn *et al*., 1975; Dexter, 1984; Dexter, 1985; McLachlan, 1990). However, these schemes have been shown to only be reliable for the specific beach or beaches that the study was done on and not applicable to beaches in other locations (McLachlan and Jaramillo, 1995). Furthermore, they make little sense, given the mobility of the animals at different temporal scales (see above).

Schemes that use physical factors to define different habitats on sandy beaches have been used on a large variety of beaches and have met with some acceptance. Salvat (1964) proposed a four zone classification based on the levels of interstitial water retention and movement at different shore levels: (i) drying sand, (ii) a zone of water retention, (iii) a resurgence zone, and (iv) a saturated zone. Brown (1983) used a simplified version of this scheme, proposing that there were only two universal zones on sandy beaches: a zone of air-breathers and a zone of water-breathers. This scheme has been accepted as the most applicable and rigorous scheme for sandy beaches (Raffaelli et al., 1991; McLachlan and Jaramillo, 1995).

1.3.2. Key Population Studies

There has been a number of general descriptive studies on the macrofaunal communities on Australian beaches (e.g. Dexter, 1983, 1984, 1985; McLachlan and Hesp, 1984; McLachlan, 1985, 1990; Haynes and Quinn, 1995, Hacking, 1996, 1998; James and Fairweather, 1996; McLachlan *et al.*, 1996b). There is far less information available on the detailed population ecology of specific organisms on these beaches (Fairweather and Quinn 1994; Fairweather 1990). While detailed studies are not available for the majority of different sandy beach organisms, the exception is for bivalves, with detailed studies done on members of the families Donacidae and Tellinidae (see Table 1.1), the mole crab *Emerita sp*. and on polychaetes within the family Spionidae. The detailed information obtained from these studies provides a valuable insight into the key biological characteristics of macrofauna which influence different species, such as competition, predation, reproduction and sediment structural support. Importantly, it has been shown that macrofauna utilising the swash zone, such as the filter feeding bivalve, *Donax serra*, form an important trophic link between the surf zone and terrestrial and offshore communities. It is unclear though whether other taxa on sandy beaches are also important in nearshore food webs

1.4. Biological Processes on Sandy Beaches

1.4.1. Competition

Although various studies have highlighted the importance of physical factors in regulating benthic populations, biological interactions may also play a role in structuring populations and communities (McLachlan *et al.*, 1993). Indeed, research has shown that inter-specific and intra-specific interactions are an important component in determining the distribution and abundance of macro-invertebrate communities on sandy beaches (Croker and Hatfield 1980; Lee, 1996; Defeo *et al.*, 1997). Using *in situ* manipulations, Lee (1996) demonstrated that two species of infaunal bivalve emigrated horizontally and vertically in response to the density of conspecifics and/or other species. Defeo *et al.* (1997) found that the patterns of distribution for some taxa could not be understood by a simple animal-sediment relationship, with evidence suggesting that the cirolanid isopod *Excirolana braziliensis* is displaced towards coarse sands and upper beach levels by its congener, *E. armata*. Haynes and Quinn (1995) also found significant temporal differences existed in infaunal densities and species richness between most beach heights, and suggested that these differences were related to variations in the densities of common intertidal species, with competition for space causing shifts in the distribution of some species. Inter- and intra-species competition may also be directed related to the tidal regime dominating a specific beach. McLachlan *et al.* (1996b) found that where tides play a greater role than wave action at the land-water interface (macro-tidal regimes), the intertidal habitat becomes more benign, leading to greater species diversity. They argued that under these conditions biological interactions played a stronger role in community organization, than on micro-tidal, wave-dominated beaches.

1.4.2. Predation

Predation by fish and birds has been suggested as an important factor regulating the abundance of macro-infauna on sandy beaches (e.g. Jaramillo *et al.*, 1980). Layman (2000) investigated fish assemblages on Virginia barrier islands and found that numerous fish utilise the shallow surf-zone and suggested that this behaviour may serve to provide the fish with access to an under-utilised food resource on the beaches and/or reduce their encounters with predators unable to access the shallow water. On a sandy beach off the Scottish coast, Ansell *et al.* (1999) found that surf zone fish fed extensively on intertidal bivalves and that between 2.5-18 % of *Donax vittatus* showed damage to their siphons, caused by non-lethal predation by juvenile flatfishes. Takahashi *et al.* (1999) determined that in the surf-zone of a sandy beach (in northeastern Japan) the dominant part of the diet of surf zone fishes consisted of intertidal, sand-burrowing peracarid crustaceans.

Crabs are also active predators on sandy beaches (demonstrated from research conducted along South Spain and the French Atlantic coast) and Salas *et al.* (2001) concluded that *Donax sp.* was subjected to sub-lethal predation (through foot-nipping – removal of parts of the large muscular foot) by crabs, with *Portunus latipes* being the most active predator. The bivalves recover from the effects of the sub-lethal predation within a 10 day period, re-growing or repairing the damaged body part (Salas *et. al.*, 2001). Swimming crabs belonging to the genus *Ovalipes* occur worldwide along sandy coastlines of subtropical and temperate waters and are significant predators of commercially important molluscs on sandy beaches (Du Preez, 1984). In a study in Japan, Takahashi and Kawaguchi (2001) identified *Ovalipes punctatus* as an opportunistic, broad-spectrum predator of sandy beaches, consuming primarily intertidal, sand-burrowing peracarid crustaceans (e.g. isopods and amphipods). Predation by naticid gastropods is a well-described component of many soft-bottom food webs, with over 80 families of gastropods and bivalves (mainly restricted to soft-substrate taxa) counted among their prey (Kabat, 1990). These predators have been the focus of many studies because the shell of their prey remains intact with an obvious bore-hole scar (reviewed by Kabat, 1990) whose size has been shown to correlate with the size of the predator (Ansell, 1982).

1.4.3. Reproduction

A common feature of many sandy beach organisms is continuous reproduction, with many showing two reproductive peaks over the year. Donacid bivalves have asynchronous sexual cycles, with continuous but partial, individual spawnings during the winter and spring months (Tirado and Salas, 1999). This pattern is similar for the tellinid bivalves, that display an extended spawning period from late spring to summer (Baron and Ciocco, 2001). Spionid polychaetes on the sandy beaches of Brazil have continuous reproduction, with spawning peaks in April and October (Souza and Borzone, 2000). Onuphid polychaetes on Australian beaches also have year-long spawning (Paxton, 1979), with reproductive peaks in February and October (Black, 1997; Fielder and Heasman, 2000). Likewise, the sand crab *Emerita sp.* exhibits continuous reproduction (Veloso and Cardoso, 1999) with two pulses of recruitment in February-March and October-December (Contreres *et. al.*, 2000). Defeo and Cardoso (2002) also found that mole crab (*Emerita brasiliensis*) populations on dissipative beaches have a longer reproductive season than in reflective beaches, in addition to higher growth performance, fecundity and somatic weight at size.

Following spawning and fertilisation of the oocytes, there is usually a larval stage that travels in ocean currents before recruitment occurs. The eggs of *Emerita sp.* are released immediately following periods with large waves and extensive water movement, presumably facilitating avoidance of predation on the eggs within the surf zone (Amend and Shanks, 1999) and increased dispersal of the larvae and gene flow between conspecific populations (Tam *et. al.*, 1996). In donacids, the larvae can travel huge distances and it has been shown that gene flow along the eastern coast of Australia is so extensive that the entire east coast should be considered and managed as a single fishery/population (Murray-Jones and Ayre, 1997).

1.4.4. Sediment structural support

The distribution of some sandy beach organisms may be determined by the deposition or presence of algae on the beach, providing either a food source or structural support within the sediments. Donacids have been shown to be more abundant on beaches with stranded kelp than on beaches without it, possibly linked to the effects of the kelp on the foraging and feeding of the bivalves (Soares *et. al.*, 1996). Drift kelp has been identified as an important food source for onuphid polychaetes (Kim, 1992). Dugan *et al.* (2003) demonstrated that macrofaunal species richness and abundance was significantly positively correlated with the abundance of drift kelp (macrophyte wrack) but was not predicted by the beach morphodynamic state or other physical factors. They also determined that beach grooming (removal of deposited wrack by management agencies) depressed species richness, abundance, and biomass of macrofauna (especially wrack-associated species). Research has also shown the importance of clusters of *Diopatra cuprea* (Polychaeta: Onuphidae) tubes in providing a biological refuge to some infaunal species, such bivalves, from predation by crabs such as *Callinectes* (Ban and Nelson, 1987). The presence of macroalgae beds have also been shown to be important in determining the structure and composition of polychaete assemblages (Marques and Ruta, 2000).

1.5. Australian beachworms

To date, very little research has been done on Australian beachworms (Family: Onuphidae). In fact, over the last 25 years, only five scientific publications have been written dealing specifically with Australian beachworm species (Paxton, 1979, 1986, 1996; Black, 1997; Fielder and Heasman, 2000). The following review of Australian beachworm biology provides species-specific information where possible, but if information is unavailable, generalisations are made using information from other Onuphidae species (based on research done elsewhere). It is important to note that, due to the wide ranging nature of the habitats that Onuphidae species occupy, any generalisations made from other members of the family may have limited applicability to the Australian species.

One possible reason why Australian beachworms have not been the focus of many studies is because of the dynamic and mobile nature of their habitat. Sandy beaches frequently change in structure from one tide to the next, making it difficult to use conventional scientific methods that rely on repetitive and standard observations. Furthermore, the worms are not restricted to permanent tubes, so they are very mobile within the substratum. Other members of the family Onuphidae that reside in permanent tubes, within a minimally changing substratum, have been the focus of extensive studies e.g. *Diopatra sp.* (Paxton and Bailey Brock, 1986; Ban and Nelson, 1987; Kim, 1992; De Leon Gonzalez, 1994; Fadlaoui *et al.*, 1995; Paxton *et al*,. 1995).

1.5.1. Distribution

Onuphidae have a worldwide distribution and occur on all kinds of substrata, from the intertidal, down to abyssal depths (Paxton, 1986; Gonzale-Ortiz *et al.*, 1997; Glasby and Alvarez, 1999). However, Australian beachworms are limited in their distribution to the intertidal and subtidal zones of sandy beaches although they are widely distributed along the east and south-east coasts of Australia (Figure 1.1). They are commonly found from Yeppoon (Queensland) to Noarlunga (South Australia) (Paxton, 1986; Bennett, 1992). Beachworms generally have a patchy distribution, with patches most commonly associated with beach sections containing gentle slopes and long swash periods (Black, 1997).

1.5.2. Morphological description

Australian beachworms were first described by Ehlers (1868) as *Diopatra teres* (Paxton, 1979). They are typically very large and are commonly greater than 1.5 m in length (Hedley, 1915; Child, 1968; Paxton, 1979; Bennett, 1992). Currently, Australian beachworms are placed in the family Onuphidae, which contains three genera, *Australonuphis, Onuphis* and *Hirsutonuphis*, and eight described species (Paxton, 1979, 1986, 1996). Common names are based on the physical characteristics of the beachworms, such as size and extent of mucus production (e.g. 'kingworms' and 'slimeys') and colouration (e.g. 'stripeys'). These names are commonly used as descriptors by local fishermen (Paxton, 1979) and can be used as a basic means of species recognition (Table 1.2).

Unlike other members of the family Onuphidae, Australian beachworms do not secrete permanent tubes. Instead, they rely on a mucus secretion to create a thin and ephemeral tube which strengthens their temporary burrows and provides protection from abrasion (Paxton, 1979; Fielder and Heasman, 2000). These mucus secretions have been termed 'temporary tubes', 'fragile tubes', 'temporary burrows' and 'mucus sheaths' by various authors (Paxton, 1979; Black, 1997; Fielder and Heasman, 2000).

1.5.3. Diet

Information on the feeding patterns of Australian beachworms is mainly anecdotal. It has been proposed that they are omnivores, relying on a staple diet of wave deposited detritus, primarily comprising drift algae, supplemented with animal matter such as crustaceans, molluscs (especially clams such as the surf clam *Donax deltoides*) and fish carcasses (Paxton, 1979; Fielder and Heasman, 2000). Another member of the Onuphidae family, *Diopatra ornate,* utilises drift kelp as its primary food source (Kim, 1992). Kim (1992) illustrated the important role drift kelp played on influencing population dynamics of this species, by showing that a decrease in the availability of drift kelp resulted in a corresponding decrease in the growth rate of the worms. While it is likely that Australian beachworms make use of drift kelp and algae as a food source, their ability to move within the substrate and forage, indicates a more non-specific, omnivorous feeding style, in which meiofauna may play an important role as dietary items (Fielder and Heasman, 2000).

1.5.4. Reproduction

Worms of the family Onuphidae have separate sexes and Australian beachworms produce gametes in the middle third of their bodies (Paxton, 1979). Mature eggs are found floating freely in the coelomic cavity and have a diameter between 220-280 μm; sperm are 40-50 μm long with head sizes between 4-5μm wide (Paxton, 1979). However, in each case gamete size varies depending on the specific species. Paxton (1979) reported that mature gametes of *Australonuphis sp.* are found throughout the year, indicating year long spawning. However, Black (1997) reported a peak mean egg diameter for *A. teres* in February and *A. parateres* in October and suggested that beachworms are semi-continuous breeders with defined breeding peaks. To date, no conclusive information exists on where or when fertilisation occurs and larval development and recruitment (to ocean beach beachworm populations) has yet to be documented.

Other members of the family Onuphidae have been shown to have a sperm transfer system involving spermatophores and seminal receptacles (Hsieh and Simon, 1990). This sperm transfer mechanism is found in the permanent tube dwelling species *Kinbergonuphis simoni,* which has a fertilisation efficiency of 98.9 % (under laboratory conditions). The fertilised eggs then develop as broods within the maternal tube. After one breeding season, the adult worms die, living for no longer than two years (Hsieh and Simon, 1991). Several other species of the family Onuphidae have been reported to produce broods of eggs which develop in the maternal tube, including: *Diopatra Marocensis* (Fadlaoui *et al.,* 1995; Paxton *et al.*, 1995); *D. brevicirris* and *D.*

madeirensis (Paxton *et al.*, 1995). However, the remaining Onuphidae species do not use maternal brooding, and instead possess a pelagic larval stage e.g. *D. cuprea* and *D. neapolitana* (Paxton *et al.*, 1995). The use of a pelagic larval stage seems most likely for Australian beachworms, because the dynamic nature of their habitat and their use of semi permanent tubes would not provide them with the environmental refuge necessary for brooding. Additionally, their sperm are not reported as spermatophores, but rather as a primitive swimming type (Paxton, 1979) suggesting that fertilisation is external, with release of both male and female gametes into the water column in a synchronous spawning event. The fertilised eggs probably develop within the water column as pelagic larvae, until they are ready to settle on sandy ocean beaches. This in part, may account for the patchy distribution of Australian beachworms, as their recruitment would depend on tidal currents and deposition patterns. Planktotrophic larvae of other polychaete worms respond to chemical cues of other polychaetes during settling (Hsieh, 1994). So it is possible that the larval stage of Australian beachworms settle preferentially on beaches already containing adult members of the species.

1.6. Fisheries on sandy beaches

Historically, sandy beach fauna have been well known for supporting fisheries. Indigenous coastal populations have a long history of collecting molluscs, crustaceans and polychaetes for food while more recently, collection of organisms for both food and bait fisheries has continued, both commercially and recreationally. In Australia, there have been very few studies examining sandy shore communities in relation to their fisheries resources (see Table 1.3). However, the results from some of this research raised concerns about the harvesting of pipis (*Donax deltoides*) from sandy shores in New South Wales (NSW), resulting in the introduction of a bag limit of 50 individuals (NSW Fisheries, 1998).

The few species of bivalve that are collected in Australia and sold in relatively small volumes for both food and bait include the pipi (*Donax deltoides*), the "cockle" *Katelysia spp* and the mud cockle (*Anadara trapezia*). Collection of bivalves for food is not a major industry on Australian sandy beaches mainly because few edible species have commercially viable populations (Ponder *et al*., 2002).

Recreational fishing is a very popular activity in Australia and a variety of invertebrates, including beachworms, are used for bait. Exploitation of invertebrates may remove a considerable biomass of the target species, especially from the accessible intertidal zone, which can result in changes in the population dynamics of beach ecosystems, but there is little information available for Australia's sandy beaches. Therefore, it is vital that more research into the resources available from sandy beach is done, to ensure that their fisheries can be managed in a sustainable manner.

1.6.1. Australian beachworm fisheries

The great length and muscular body of Australian beachworms make them appealing to fisherman as a common source of bait and they are collected by the millions by recreational fishermen and professional collectors (Ponder *et al.*, 2002). Worm collectors attract worms to the surface by dragging burley, either oily fish or shark skin, through the receding swash. Then the worms are offered a small piece of bait (usually the fleshy part of a pipi) and they are subsequently collected one worm at a time by grasping them behind the head and pulling them out of the sand (Paxton, 1979; Bennett, 1992). Fishers tend to work only during daylight low tides, concentrating on the last 2 hours of ebb and the first hour of rising tide; preferring to fish on gently sloping beaches with gentle swash (Fielder and Heasman, 2000). The non-destructive nature of the collection method combined with the removal of mainly large individuals, means that even on beaches that have been heavily harvested, worms are still plentiful (H. Paxton personal communication - cited in Ponder *et al*., 2002).

A semi-regulated professional fishery exists in the northern regions of the Australian beachworms distribution (in Queensland and NSW) and focuses mainly on the two species *A. teres* and *A. parateres*, but also includes the smaller *H. mariahirsuta* (Paxton, 1986; Fielder and Heasman, 2000). While has not yet been any analysis of the commercial catch for the Queensland regions, Fielder and Heasmen (2000) recently completed an extensive review of the NSW fishery over the period 1991–1996.

On the northern coasts of NSW, the commercial beachworm-gathering fishery is a small but increasing fishery, valued at A$563,250 for the 1995/96 season. Total annual beachworm catches in NSW has increased steadily from 3.3 t in 1990/91 to 11.3 t in 1995/96 (Fielder and Heasman, 2000). Analysis of catch per unit effort data over this period indicated no evidence that over-fishing of beachworm populations had taken place. Maximal catches were observed during spring and summer months, coinciding with bait demand by recreational fishers (Fielder and Heasman, 2000). The relative importance of recreational worm collecting has not yet been evaluated, however NSW fisheries has imposed a bag limit of 20 worms per day (Fielder and Heasman, 2000). So far, bag limits have not been used in the Queensland fishery. A leading polychaete biologist/taxonomist considered that the current Australian beachworm bait fisheries appear to be sustainable (H. Paxton personal communication - cited in Ponder *et al*., 2002), although the basis for this assessment was unclear. It was recommended that action should be taken to restrict the collection of beachworms to the present method and not allow mechanical mass collection of worms from the beach.

Currently, significant gaps exist in knowledge about the basic biology and ecology of beachworms, including a lack of information on their reproductive cycles, developmental biology, recruitment, diet, population densities and the impacts of recreational and commercial fishers. There is an obvious need for more information and research on this valuable fisheries resource, in order for sustainable and biologically sound management measures to be devised and implemented. Ponder *et al.* (2002) suggested that the primary reasons why so little research has been carried out on Australian marine invertebrate fauna was due to: (1) a chronic lack of resources for basic taxonomic, biological and ecological studies; (2) a lack of, or minimal involvement in, and consideration of, invertebrate studies, by government agencies responsible for marine research; and (3) a weakening of basic invertebrate biology and diversity courses in many universities.

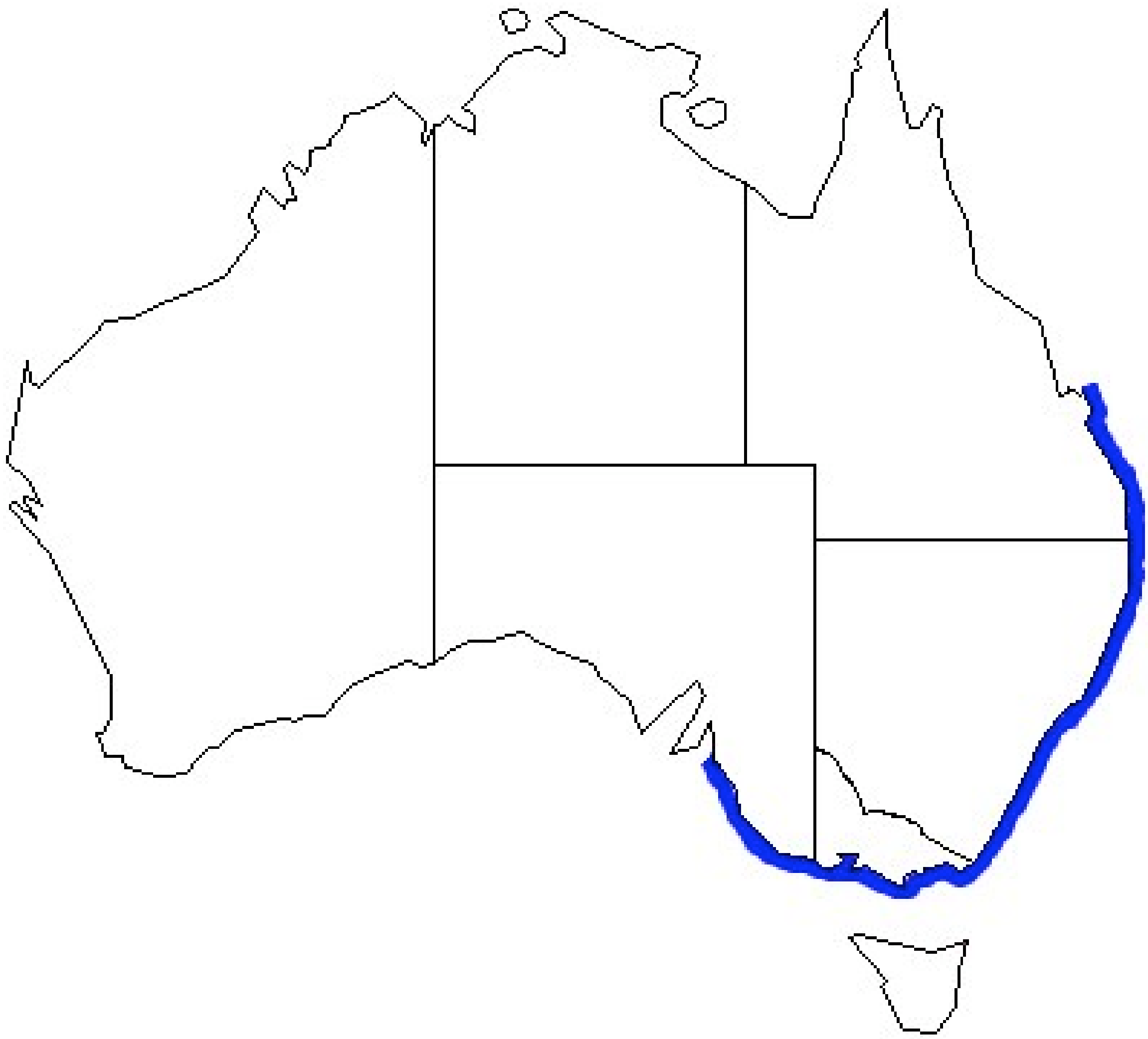

Figure 1.1. Geographical distribution of Australian beachworms of the family Onuphidae.

Table 1.1. Examples of population studies done out on selected animals on sandy beaches. This is not meant as an exhaustive list, but will enable the reader to break into the relevant literature.

Class	Family	Species	Study	References
Bivalvia	Donacidae	*Donax sp.*	Biology/Ecology Predation	McLachlan *et al.*, 1996 Salas *et al.*, 2001
		D. deltoides	Reproduction	Murray-Jones and Ayre, 1997
		D. serra	Recruitment Ecology	Lastra and McLachlan, 1996 Dugan and McLachlan, 1999
		D. venustus and D.semistriatus	Reproduction	Tirado and Salas, 1999
		D. vittatus	Predation	Ansell *et al.*, 1999
	Tellinidae	*Tellina lineata, and T. versicolor*	Predation	Arruda *et al.*, 2003
		T. petitiana	Reproduction	Baron and Ciocco, 2001

Table 1.2. Australian beachworms of the family Onuphidae and their common names (Paxton, 1979, 1986, 1996).

Genera	Species	Common Name
Australonuphis	*teres*	Kingworm / Stumpy
Australonuphis	*parateres*	Slimey
Onuphis	*taeninata*	Stripey
Hirsutonuphis	*gygis*	Giant
Hirsutonuphis	*mariahirsuta*	Wirey / White headed wirey
Hirsutonuphis	*armillata*	No common name
Hirsutonuphis	*marocerata*	No common name
Hirsutonuphis	*intermedia*	No common name

Table 1.3. Types of fisheries occurring on sandy beaches worldwide.

Species harvested	Used for	Location	Reference
Beachworms (*Australonuphis sp.; Onuphis sp.*)	Bait	Australia - Eastern Coast	Paxton, 1996; Fielder and Heasman, 2000
Pipis (*Donax deltoides*)	Food Bait~2%	Australia - East coast	Murray-Jones and Steffe, 2000
Pipis (*Donax deltoides*)	Food	Australia - NSW	NSW Fisheries, 1998
Crabs (*Birgus latro; Scylla serrata*) Rock lobsters (*Panulirus spp.*) Spider shells (*Lambis spp.*)	Food	Australia - Cocos (Keeling) Islands	Caton *et al.*, 1998
Clam (*Mesodesma donacium*)	Food	Chile - Arica to Chiloé Island	Tarifeño, 1980 cited in Fernandex *et al.*, 2000
Cockles (*Cerastoderma edule*)	Food	Britain - Auchencairn bay	Hall and Harding, 1997
Crabs (*Ocypode sp.; Emerita sp.; Hippa sp.)*	Bait	South Africa - Northern KwaZuluNatal	Kyle *et al.*, 1997
Yellow Clam (*Mesodesma mactroides*)	Food	Uraguay - Eastern coast	Brazeiro and Defeo, 1999

Chapter 2: Beachworm fisheries

The primary aim of this part of the study was to describe the commercial and recreational fishing effort in the beachworm fishery in SE Queensland. The recreational and commercial beachworm fisheries were examined separately. The examination of the recreational fishery was based on two creel surveys of the fishers participating in the Fraser Island Fishing Classic in 2000 and 2001. The examination of the commercial fishery was based on analysis of commercial beachworm fisheries data, obtained from the Queensland Fishery Service.

Recreational Fisheries

2.1. Methods

A creel survey (Table 2.1) was administered to recreational fishers participating in the annual Fraser Island Fishing Classic over a three day period in two consecutive years, May 2000 and May 2001. The survey consisted of 20 questions chosen to determine the bait that was harvested by fishers and the type of bait used by the fishers. Fraser Island is a popular beach fishing destination and has a large beachworm population, making it a suitable location for collecting information about recreational beachworm fisheries.

Interviewees were chosen by driving along the beach and interviewing every person participating in a fishing or bait collecting activity. The questionnaire was administered while the fisher continued fishing or bait collecting. It was evident that there were two main groups of respondents to the questionnaire: those that harvested beachworms for use in the fishing competition (hereafter referred to as harvesters) and those that did not harvest the worms (hereafter referred to as non-harvesters), even though they may have used beachworms that were purchased or obtained elsewhere. During the 2000 competition, approximately 1100 people registered in the fishing competition and about 9 % (n = 96) of the fishers were surveyed. In the 2001 competition, approximately 1200 fishers registered in the event, of which 12 % (n = 139) were surveyed. It should be noted that not all participants in the Fraser Island Fishing Classic fish from the shoreline and that beachworms are primarily use by those fishers operating from the shore. This means that the number of participants that were surveyed in 2000 (n=96) and 2001 (n=139) probably represent a larger proportion of those fishers that were shore-based (and using beachworms) than the total number of registrants in the competition.

2.2. Results

Analysis of the frequency that respondents went fishing indicated that 69 % of all fishers in 2000 and 71 % of all fishers in 2001 only fished once a month or even less regularly (Figure 2.1). There were no obvious differences between harvesters and non-harvesters in the frequency that they went fishing in either of the two years. For those fishers that harvested beachworms, there were two main groupings in relation to their fishing activity. One group included those fishers that harvested beachworms on a regular basis (monthly or more often, 32 % for 2000 and 18 % for 2001). The other, larger group of fishers primarily harvested beachworms during their holidays (i.e. less frequently than once per month; 68 % for 2000 and 82 % for 2001) (Figure 2.2).

In 2000, most of the fishers that harvested beachworms (59 %), did so for less than 40 % of their fishing trips, while only 23 % harvested worms on 60-100 % of their fishing trips (Table 2.1). In contrast, in 2001, most harvesters (52 %) collected worms for use on 60-100 % of their fishing trips. There was also a slight difference between years in the size of groups harvesting worms. In 2000, most beachworm collectors (68 %) harvested worms in groups of two or more, while the following year 61 % of collectors worked alone (Figure 2.3).

The main fish species targeted using beachworms were summer and winter whiting (*Sillago ciliata* and *S. maculata*), dart (*Trachinotus botla*), bream (e.g. *Acanthopagrus australis*) and flathead (*Platycephalus* spp.) (Figure 2.4). Only a few fishers used beachworms to target jewfish (Family: Sciaenidae), trevally (Family: Carangidae e.g. *Caranx ignobilis*) or tailor (*Pomatomus saltatrix*). Beachworms were rarely used as a non-specific bait. Seventy-one percent of the fishers in 2000 and 58 % of the fishers in 2001 who used beachworm for bait used 10 or less worms per day, while only 3 % of fishers (for both 2000 and 2001) used more than 20 beachworms (Figure 2.5).

Seventy-nine percent of the fishers in 2000 and 53 % of the fishers in 2001, harvest between 1-10 worms per harvesting session, while only 3 % in 2000 and 13 % in 2001 harvested more than 20 worms per session (Figure 2.5). The length of beachworm most commonly captured by fishers in 2000 was between 51-75 cm but in 2001 was between 51-100 cm in length (Figure 2.6). In 2000, the length of worms that was targeted by harvesters coincided with the length of beachworm that were collected. In 2001, fishers had a preference for larger (76-100 cm) worms.

A number of different bait types were harvested by fishers, even though they were primarily targeting beachworms. In fact, 97 % of all fishers surveyed (from both years combined) harvested bait of some kind, with 76 % harvesting at least two or more types of bait (Figure 2.7). The most common bait used by all fishers were pipis (*Donax deltoides*), followed by beachworms, and then yabbies (*Trypaea australiensis*) (Figure 2.8, Table 2.2). On average, fishers used other bait sources 17 % of the time in 2000 and 14 % of the time in 2001. The number of fishers using the three dominant bait types was only slightly greater than the number of fishers harvesting them. The one exception to this was beachworms; the number of fishers who used them in 2001 was nearly double the number who collected them.

Fishers harvesting beachworms used beachworms as the most common bait followed by pipis then yabbies (Figure 2.9, Table 2.2). Beachworms were primarily obtained from three sources. The main one was beach harvesting (79 % in 2000, 57 % in 2001), followed by purchasing them from shops (48 % in 2000, 44 % in 2001), or obtaining them from friends or fellow fishers (10 % in 2000, 19 % in 2001) (Figure 2.10). Of the fishers who harvested their own beachworms in the 2000 survey, 83 % harvested more than half the worms they used as bait, while 54 % collected all the worms they used (Figure 2.11 – note, no data were available for 2001). Once beachworms have been obtained by fishers, 43 % (in 2000) and 30 % (in 2001) of fishers planned to fish with them within 6 hr, and 84 % (in 2000) and 64 % (in 2001) within 24 hr. In the 2000 survey, only 1 % of fishers preserved worms for use at a later date (Figure 2.12). However, results from the 2001 competition suggest that a greater number of fishers (23 %) use preserved worms.

Of the seven beachworm species available to fishers in Queensland, only three species were used commonly by fishers in 2000 and 2001. These were Slimeys (*Australonuphis parateres*), Stumpies (*A. teres* - juveniles), and King worms (*A. teres* - adults) (Figure 2.13). Slimeys and Stumpies were preferred by 92 % of the fishers who used beachworms in 2000 and 2001, and fishers showed no significant preference between these two species (Figure 2.14) (Chi-squared test, $p > 0.05$).

2.3. Discussion

The fishers surveyed during the Fraser Island Fishing Classic were considered to be dedicated fishermen compared with recreational fishers in general. They tend to have a greater level of specialist knowledge and expertise and a higher level of dedication to the sport. The effects of bait collection for recreational fishing has largely been ignored to date (McPhee and Skilleter, 2002) and the findings from this study show that beachworms play an important role in recreational fishing on sandy beaches . Nearly all the participants in the tournament collected their own bait and 50 % and 67 % of the fishers from the 2000 and 2001 event respectively, collected some of their own beachworms for bait. The two species of beachworms primarily targeted were Slimeys (*Australonuphis parateres*) and Stumpies (*A. teres*)). In general, beachworms were the second most frequently used bait type (after pipis), but those fishers who harvested beachworms, preferred to use them as their main choice of bait. Most fishers using beachworms as bait were using them to target estuary and shoreline species such as whiting (*Sillago* spp.) and yellowfin bream (*Acanthopagrus australis*). Both of these species are the numerically dominant species caught by recreational anglers in Queensland (Higgs, 1999).

In both years, the lengths of the beachworm most commonly captured correlated with fisher's preference. All fishers preferred to use medium to long worms (25 – 100 cm) which is reflected by their preference for Slimeys (average length 75-150 cm) and Stumpies (average length 25-75 cm). Only a small number of beachworms were caught and used per fisher, with most beachworm fishers using less than 10 worms in a days fishing. Most beachworm harvesters also collect less than 10 worms in a worm harvesting session and use them within 48 hours. This suggests that even though beachworms are a commonly used bait item, only small numbers are used per fisher. Consequently, if a bag limit of 10-20 worms per fisher was introduced in Queensland, only a small proportion of fishers would be negatively affected. In summary, the average fisherman uses only small numbers of worms (< 10) and uses most of them soon after capture. Lastly, as mentioned before, very few fishers use beachworm as a non-specific bait indicating the degree of expertise of the fishers. Usually, individual recreational fishers are considered to have minimal impacts on target species because most harvest few or no fish on any outing (Hilborn, 1985). This may not apply to the harvesting of bait species, such as beachworms, and this activity needs to be considered more widely when investigating the impact of recreational fishers on the coastal environment (McPhee and Skilleter, 2002).

Looking at the distribution of those collectors harvesting beachworms regularly versus on their holidays it appears that any impacts from the recreational fishery on beachworm numbers would be predominantly seasonal, increasing around public holidays and periods of good weather, with a smaller proportion of regular, year round recreational harvesters. Results from the 2000 survey showed that most fishers harvested worms in groups of two or more while the 2001 survey indicated that most fishers collected worms alone. Regardless of the collecting habits of the two groups, those fishers who do harvest beachworms are unlikely to obtain beachworms from other sources (i.e. shops).

There are currently no other data available that would allow the results of these surveys to be compared with the patterns of harvesting and fishing across the entire SE Queensland recreational fishery. It is likely, as discussed above, that participants in this fishing competition represent a sub-group of fishers that are specifically dedicated to their sport. As such, these fishers are likely to have better equipment, more expertise and fish more often than 'average' SE Queensland recreational fishers. Accordingly, it is quite likely that a larger proportion of these fishers collect their own bait, rather than buy it, compared with less avid fishers across the state in general.

Commercial Fisheries

2.4. Methods

The Queensland commercial beachworm fishery is a regulated fishery controlled by the Queensland Fishery Service (QFS). The QFS allocates non-transferable licenses to individuals, authorizing them to collect beachworms. The licenses are known as authorities and allow the authority holder only to collect beachworms at the location(s) specified on the authority. All beachworm authority holders are legally obliged to record their catch data in a logbook at the end of each days harvesting. Details which must be recorded are the collecting location(s), the number of beachworms caught, and the number of hours spent collecting worms.

For the present study, the Queensland beachworm commercial fishery catch data were obtained from the QFS as a Microsoft Access database. To ensure anonymity, no individual fishers were identified in the dataset. A random code was used to identify each authority holder.

Fielder and Heasman (2001) carried out a study examining commercial beachworm fisheries in NSW for the years 1990 to 1996. Therefore, the results obtained from the Queensland beachworm fishery were compared with the data from the NSW fishery. The study on the NSW fishery reported beachworm catches in biomass (kg), so these data were converted to number of worms caught using the conversion weight often used by fishers to prepare catch returns, which is 50 worms to the kg (Fielder and Heasman, 2001).

2.5. Results

From February 1997 to December 2001, 34 licensed fishers were active in the Queensland commercial beachworm fishery. During the first few months of this period, only a small proportion of beachworm fishers reported catch data to the QFS (1 fisher in February 1997 and only 23 fishers until June 1997 – see Figure 2.15). After this time, the number of fishers participating in the fishery remained fairly constant and from July 1997, the average number of fishers actively fishing was 28.2 (standard deviation = 1.2). The smallest annual beachworm catch (571 000 worms) was recorded in the period 1997/98 while the largest catch (855 000 worms) was recorded in 1998/99 (Figure 2.16). Annual catch data were calculated from February to January inclusive. Annual worm catches remained at a fairly consistent level between 1997 and 2001 and there were no obvious trends evident over this time. The same was true for the total number of person days fished in each year, which ranged from 2 705 in 1997/98 to 3 531 in 1998/99 (Figure 2.17). A plot of the average number of days fished each month (Figure 2.18a) showed that the fishery undergoes a subtle seasonal cycle. Peak fishing effort is concentrated in the summer months (most notably December and January) and is least in the winter (May to July). The same pattern was shown for CPUE, which was highest in summer and lowest in winter (Figure 2.18b). Analysis of monthly catch data also illustrated the same trend, with most worms caught in summer and least in winter (Figure 2.18c). Most fishers (n = 25), harvest beachworms on less than half the days in the year, with the majority working between 50-99 days per year (n = 12). The range in annual fishing frequency between individuals was quite substantial, with a minimum of 15 and a maximum of 225 days (Figure 2.19).

Annual catch per unit effort (worms hr^{-1}) was lowest in 1997/98 (63 worms hr^{-1}) but remained at a consistent level for all other years, ranging between 74 and 77 worms hr^{-1} (Figure 2.20). CPUE varied tremendously between different fishing days, but on 80 % of fishing days CPUE was less than 100 worms hr^{-1} (Figure 2.21). The maximum recorded CPUE was 300 worms hr^{-1}.

The total number of fishers participating in the Queensland commercial beachworm fishery was much less (n =34) than those who participated in the NSW fishery (n = 52) (Table 2.3). During most months in Queensland the number of fishers actively fishing was ~ 28 fishers, while the number in the NSW fishery was slightly higher ranging between 27 and 37 fishers. Even though more fishers participate in the NSW fishery, the total days fished each year were not very different between the two fisheries. Thus despite the smaller size of the Queensland fishery (in terms of numbers of fishers) the total annual beachworm catch in Queensland is much greater than that obtained in the NSW fishery. In fact, the lowest catch in Queensland (571 000 worms) was more than the highest estimated catch in NSW (563 000 worms) and the highest Queensland catch was 50 % greater than the highest NSW catch (Table 2.3). Much greater CPUE was also recorded in the Queensland fishery, with the smallest CPUE in Queensland still five times larger than the equivalent CPUE in NSW while the largest CPUE in Queensland was more than 150 % greater than that achieved in NSW. Interestingly, despite the large CPUE in the Queensland fishery, almost three quarters of the commercial fishers involved in the fishery spent less than 100 days a year collecting worms.

2.6. Discussion

The number of active fishers in the Queensland commercial beachworm fishery was relatively small during the first few months of 1997, but then increased and numbers remained consistently large from July 1997 onwards. The reason for this increase is probably more related to patterns of reporting rather than any substantial change in the fishery: the start of 1997 coincided with the initiation of the logbook recording program. Therefore, some fishers may not have started recording their catches until a few months into the program. This might also explain why the smallest annual catch of beachworms (571 000 worms) was recorded in the first year that catch information was being recorded in logbooks. In all subsequent years, annual catches and the total number of days fished remained relatively constant. The relatively constant commercial catch of beachworms since the introduction of logbooks may also reflect the constant nature of market demand. Many commercial operators sell their catch to a limited number of bait shops and the worms are kept alive for subsequent sale to anglers. Bait shop owners are likely to keep only a limited stock on hand at any time to reduce the risk (and costs) associated with death of the stock before it can be sold. Discussion with several bait shop operators suggested this was the case, but no data were available to provide a more general assessment of this issue. The logbook data that were provided did not include any information on the number of shops to which commercial operators provided stock so a more detailed analysis of market demand in this fishery was not possible.

Fishing effort was greatest during summer and lowest throughout winter. Not surprisingly, this meant most beachworms were harvested in summer and the least in winter. It is likely that fishers tend to concentrate their fishing effort in months where the greatest CPUE is attained. In the Queensland beachworm fishery, the greatest CPUE is attained in summer and the lowest CPUE in winter suggesting that the largest densities of beachworms are found in summer and the smallest densities in the winter. Alternatively, some other seasonal factor makes it easier to catch worms in the summer (i.e. worms are more readily attracted to the surface).

Beachworm fishing in Queensland appears to be a far more lucrative enterprise than beachworm fishing in NSW, with a much higher CPUE being recorded by most fishers. Using the value per worm (A$1) from Fielder and Heasman (2001), a fisher working 200 days a year in the Queensland fishery could achieve gross earnings of A$50,800 p.a. which is almost three times the amount suggested by Fielder and Heasman (2001) for the NSW fishery. Interestingly, despite the high economic rewards to be reaped from the fishery, most of the commercial fishers in Queensland spent less than 100 days a year collecting worms. Combined with the constant annual catches this might suggest that the fishery is being exploited near its maximal sustainable yield, or instead it might simply indicate the time that fishers are able (or willing) to give to beachworm fishing.

Table 2.1. Creel survey administered to recreational bait harvesters observed collecting beachworms along the surf zone of Fraser Island during the Fraser Island Fishing Classic in each of May 2000 and 2001.

Date:.................................... **Location:**...

Arrival Time:........................ **Departure Time:**...

Interviewers:....................... **Int. Code:**...

Number of wormers/helpers/fishers:...

Car Registration Number:...

Q1a. Have you been interviewed previously about your beachworm collecting activities.

o Yes o No (go to Q.2.)

Q1b. If so when and where? ....
....
....

Q2. Approximately how often have you been fishing in the past twelve months?

o Weekly or more often o Fortnightly o Once a month

o Less often or on holidays o Unsure

Q3. Are you a member of an amateur fishing club?

o Yes o No

Q4. Do you use or harvest any of the following for bait. If you harvest, approximately in what locations:

Rock worms	o Use	o Harvest	o NR
Wriggler worms	o Use	o Harvest	o NR
Surf worms	o Use	o Harvest	o NR
Bloodworms	o Use	o Harvest	o NR
Yabbies	o Use	o Harvest	o NR
Pipies	o Use	o Harvest	o NR
Soldier crabs	o Use	o Harvest	o NR
Other	o Use	o Harvest	o NR

Locations:..
....

ALL THE FOLLOWING QUESTIONS RELATE TO BEACHWORMS

Q5. Do you use beachworms as bait or collect beachworms?

o Use o Collect

(If no response, end of survey)

Q6. Do you use beachworms in fishing club competitions?

o Yes *(please specify which):* ....

o No

Q7. Where do you obtain your beachworms from?

o Shop *(please specify):* ....

o From a friend/fellow fisher:
o From a commercial beachworm harvester
o Collect myself (please specify percent of total):
o Other *(please specify)*: ....

Q8. Approximately how soon after obtaining beachworms do you plan to use them?

o Within 6 hrs o Within 12 hrs o Within 24 hrs
o Within 48 hrs o Other (*please specify*)

Q9. Approximately how soon after obtaining beachworms do you plan to use them?

o Kingworm (*A. teres* adult) o Preferred
o Stumpy (*A. teres* young) o Preferred
o Slimy (*A. parateres*) o Preferred
o Stripey (*O. taeniata*) o Preferred
o Giant (*O. gygis*) o Preferred
o Wiry (*O. mariahirsuta*) o Preferred
o White headed (*O. mariahirsuta*) o Preferred

Q10. Approximately how many beachworms do you use in a day's fishing?

o 0-10 o 11-20 o 21-30 o 31-40 o 41-50
o > 50 (*please specify*)

Q11. Approximately how large are the beachworms you prefer to use?

o 0-25 cm o 16-50 cm o 51-75 cm o 76-100 cm o 100-150 cm
o > 150 cm (*please specify*):

Q12. Which species of fish are you targeting with the beachworms you have harvested?

o Bream o Summer whiting o Winter whiting
o Dart o Jewfish o Flathead
o Tailor o Other o Anything

ALL THE FOLLOWING QUESTIONS REALTE TO BEACHWORM HARVESTING

Q13. How many times per year do you collect beachworms?

o Weekly or more often o Fortnightly o Once a month
o Loss often or on holidays o Unsure

Q14. When was the last time you collected beachworms?

o Today o Week o Month
o 6 Months o 9 Months o 12 Months or more

Q15. Approximately what percentage of fishing trips do you collected beachworms for or on?

o ....

Q16. How many fishers do you collect beachworms for?

o ....

Q17. What locations do you harvest beachworms from?

o ....
o ....
o ....
o ....
o ....
o ....

Q18. How many beachworms did you harvest in your last bait harvesting session?

o 0-10 o 11-20 o 21-30 o 31-40 o 41-50
o > 50 (*please specify*)

Q19. Approximately how many beachworms do you harvest in a bait harvesting session?

o 0-10 o 11-20 o 21-30 o 31-40 o 41-50
o > 50 (*please specify*)

Q20. Approximately how large are the beachworms you catch?

o 0-25 cm o 16-50 cm o 51-75 cm o 76-100 cm o 100-150 cm
o > 150 cm (*please specify*):

Table 2.2. Proportion of fishing trips that fishers harvested worms for use on that trip in 2000 (n=63) and 2001 (n=52).

Proportion of fishing trips for which worms were harvested	Year	
	2000	2001
0 – 20 %	22	7
21 – 40 %	15	5
41 – 60 %	11	13
61 – 80 %	6	5
81 – 100 %	9	22

Table 2.2. Percentage of fishers who use different bait species surveyed at the 2000 and 2001 Fraser Island Fishing Classic, comparing usage between all fishers and beachworm harvesting fishers. (*Five species groups included in the mean calculation were bloodworms, soldier crabs, wriggler worms, rock worms and other species*).

	All fishers		Beachworm harvesters	
	2000	2001	2000	2001
N =	(96)	(139)	(64)	(69)
Pipis	89	93	94	97
Beachworms	82	87	100	99
Yabbies	70	68	75	73
Mean for all other species	*17*	*14*	*14*	*14*

Table 2.3. A comparison of main characteristics of two commercial beachworm fisheries in (a) Queensland (for the periods 1997/98 to 2000/01) and (b) New South Wales (for the periods 1990/91 to 1995/96 – source: Fielder and Heasman, 2001). Catch data from NSW was converted from biomass to total worm numbers by using the conversion factor of 50 worms kg^{-1}.

		Beachworm fishery	
		Queensland	New South Wales
Number of fishers participating in fishery over the entire study period		34	54
Days fished (per year)	Low	2 705	2 096
	High	3 531	3 539
Average hours fished a day (shown with standard deviation)		3.3 ± 1.5	-
Annual beachworm catch (worms numbers)	Low	571 000	167 000
	High	855 000	563 000
Annual catch per unit effort shown in worms d^{-1} (worms hr^{-1} shown in brackets)	Low	208* (63)	40
	High	254* (77)	102

* calculated by multiplying CPUE worms hr^{-1} by the average hours fished a day.

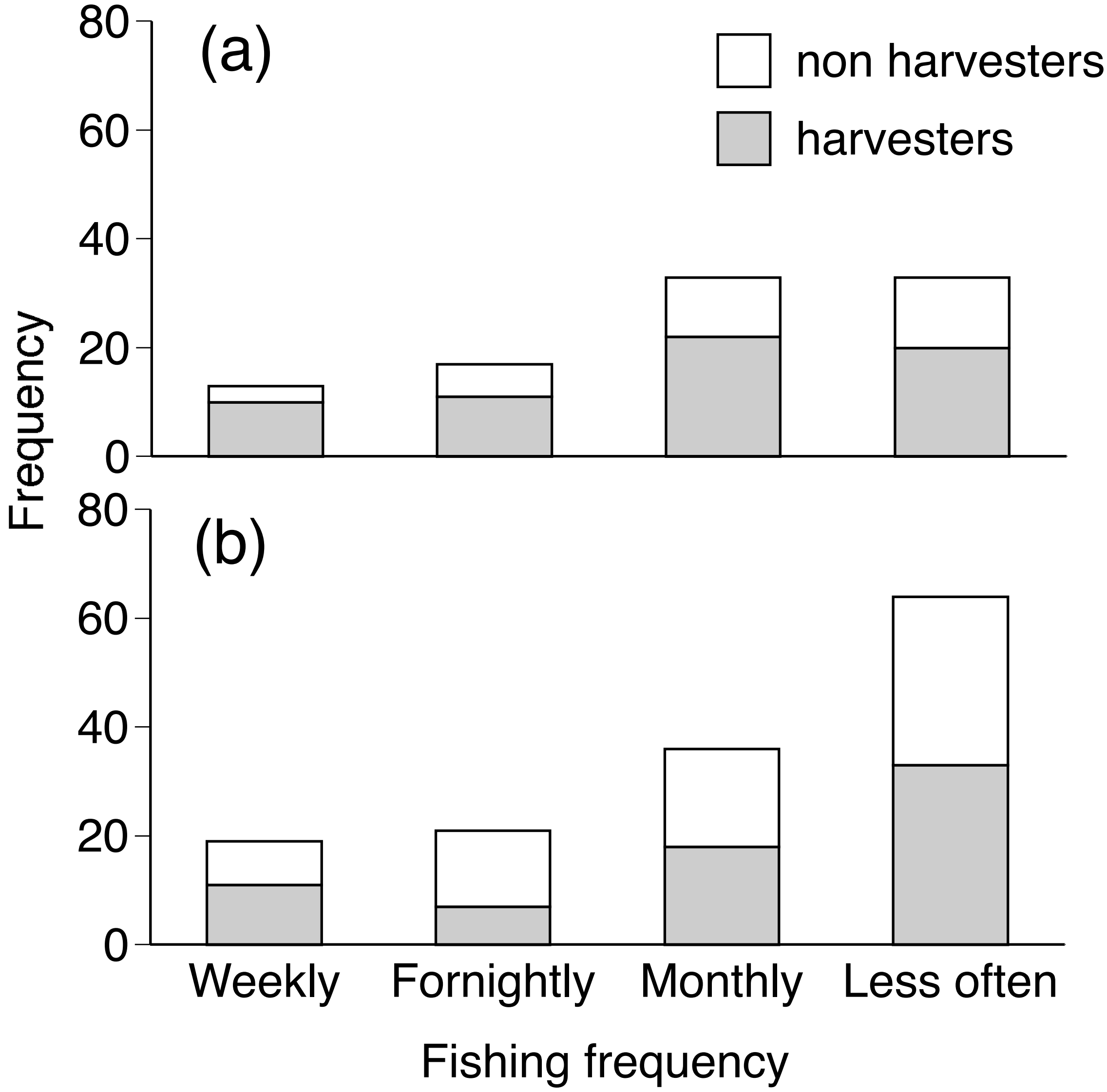

Figure 2.1: Frequency that different groups of fishes went fishing in (a) 2000 (n=96) abd (b) 2001 (n=139). Non-harvesters were those fishers that did not collect their own beachworms, even though they may have used baechworms purchased or obtained elsewhere. Harvesters collected their own beachworms for use as bait.

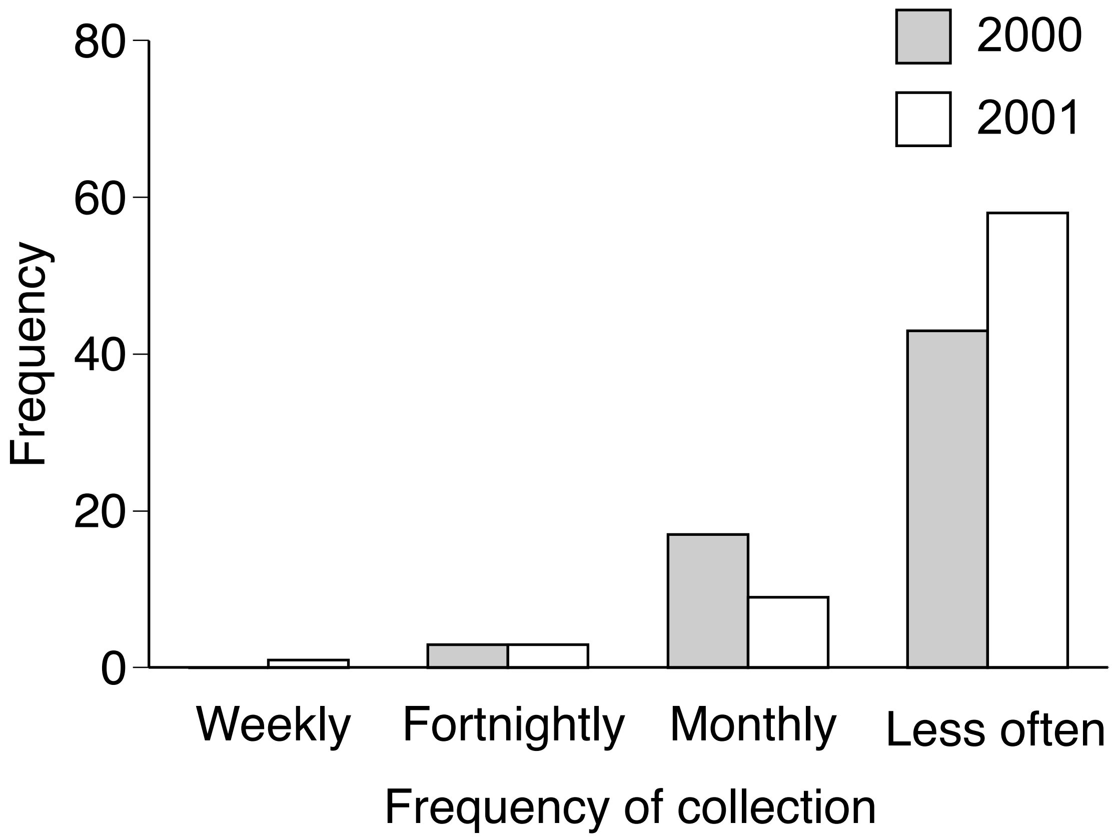

Figure 2.2: Frequency that harvesters collected beachworms for use in fishing in 2000 (n=63) and 2001 (n=69).

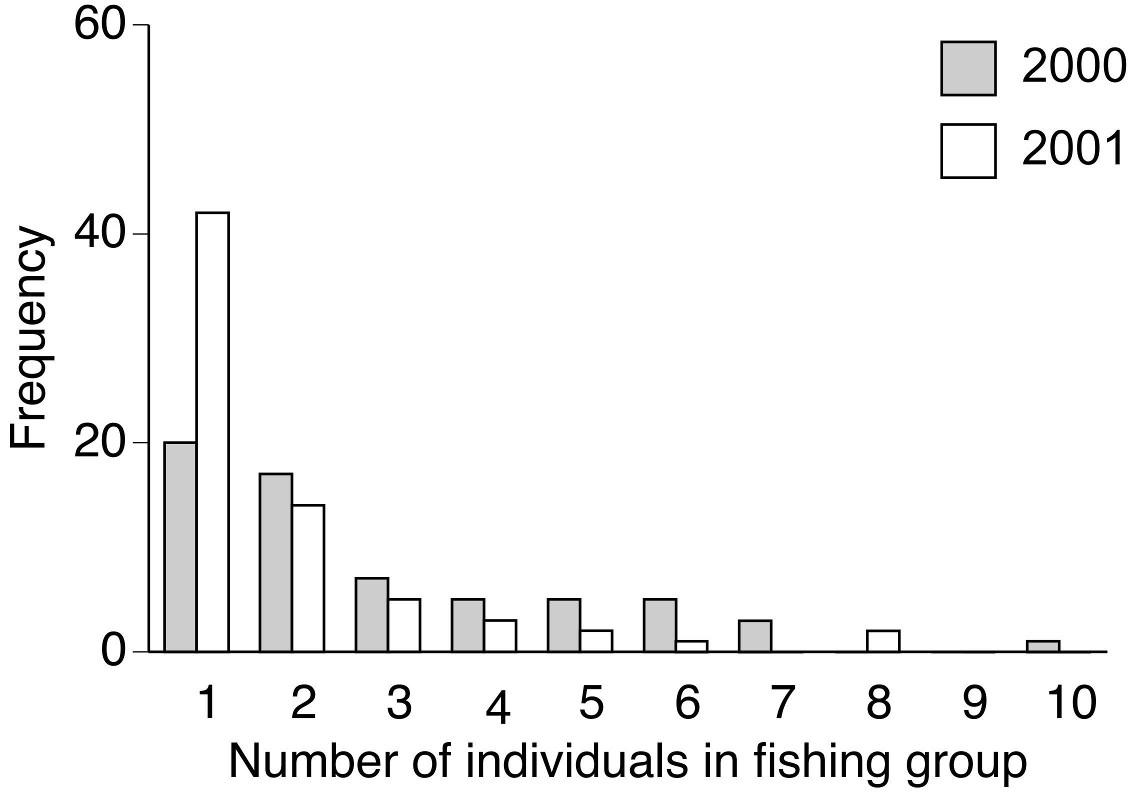

Figure 2.3: Frequency that harvesters worked in groups of different sizes when harvesting beachworms for use in fishingtrips in 2000 (n=63) and 2001 (n=69).

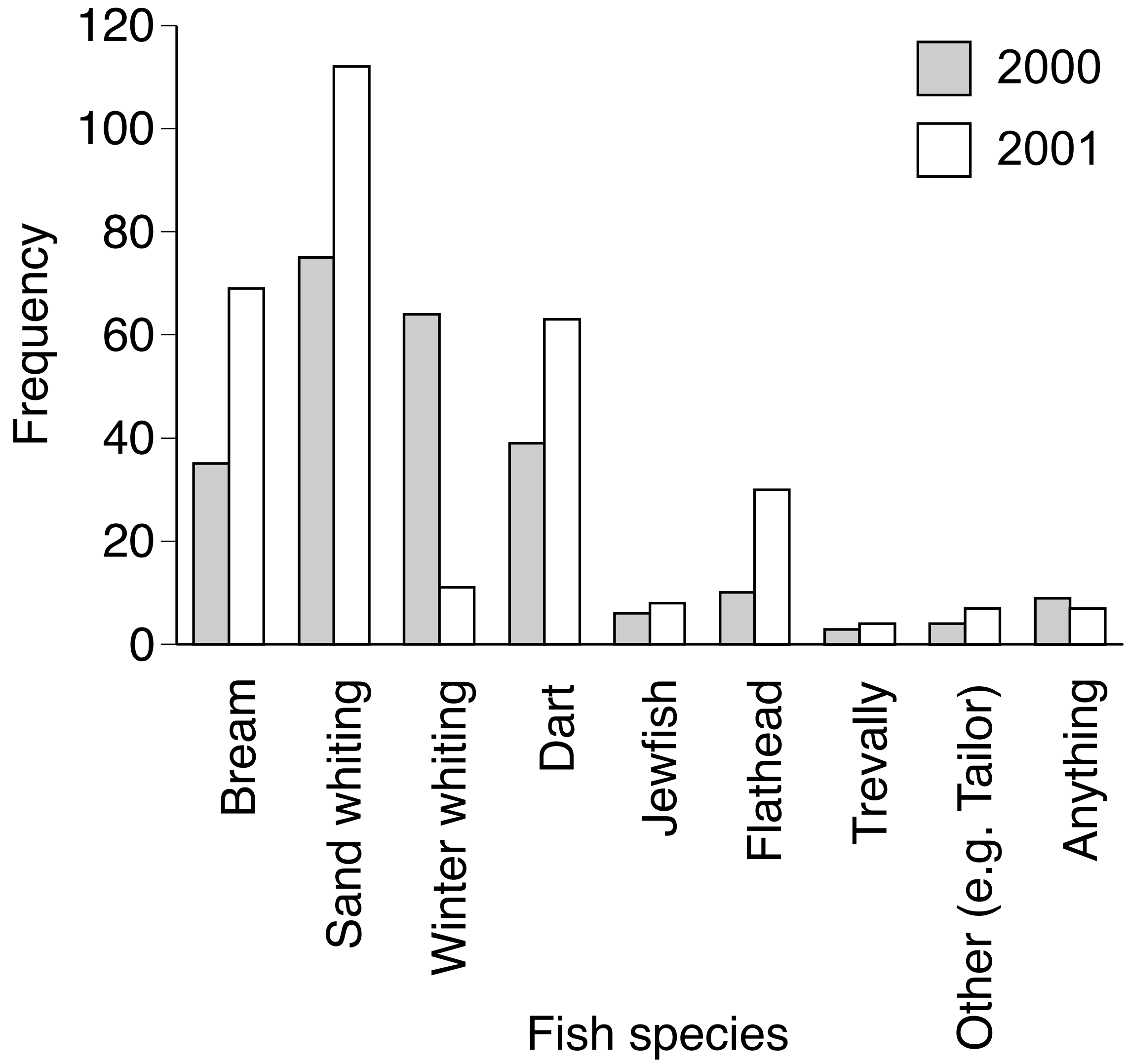

Figure 2.4: Frequency that different groups of fish were targeted by fishers when using beachworms a bait in 2000 (n=79 respondants) and 2001 (n=121 respondants). Note that fishers frequently targeted several different species on any one trip.

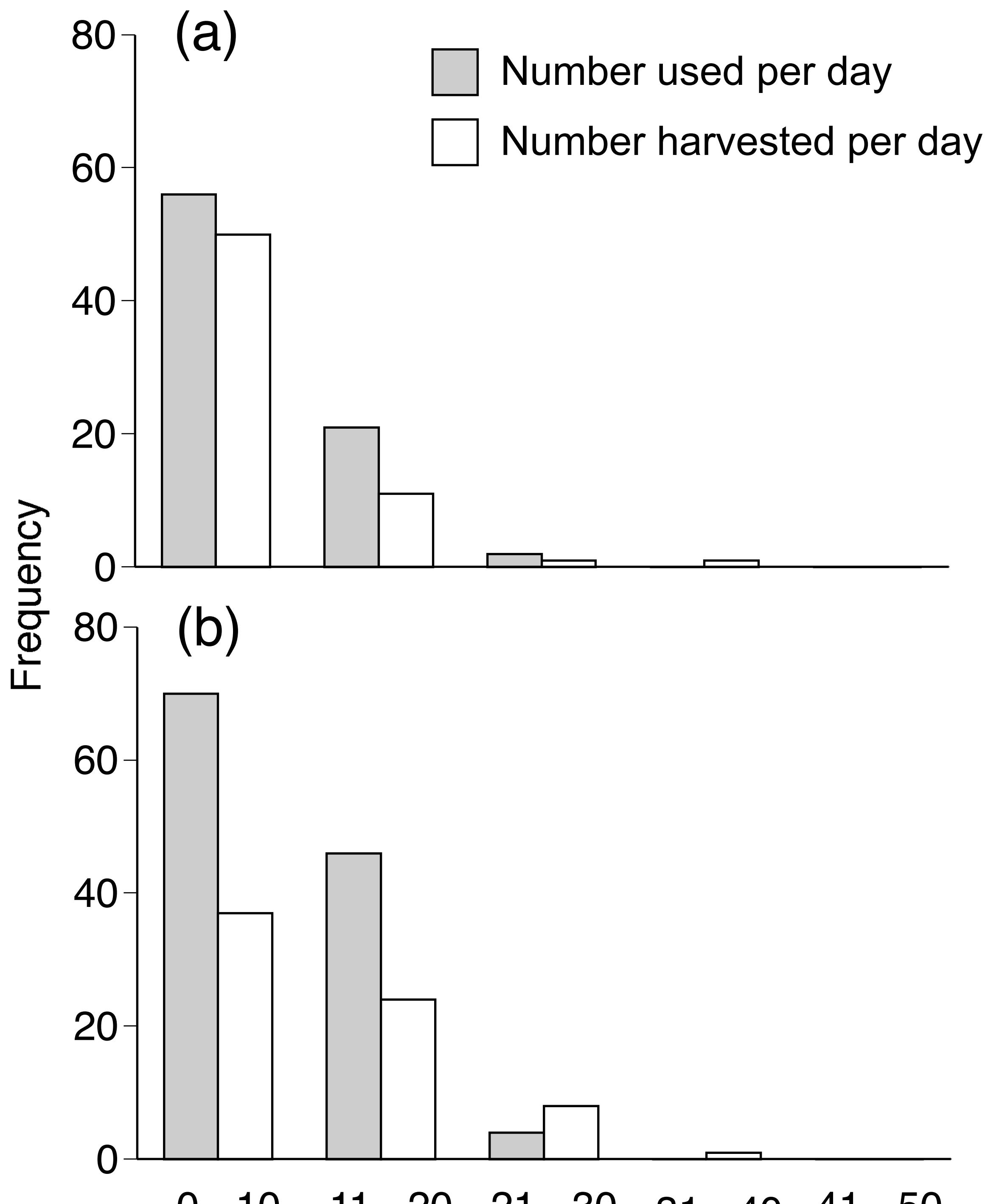

Figure 2.5: Frequency that fishers used different numbers of beachworms in any fishing trip and the frequency that different numbers of beachworms were harvested on that day in (a) 2000 - n=79 used, n=64 collected and (b) 2001 - n=121 used, n=69 collected.

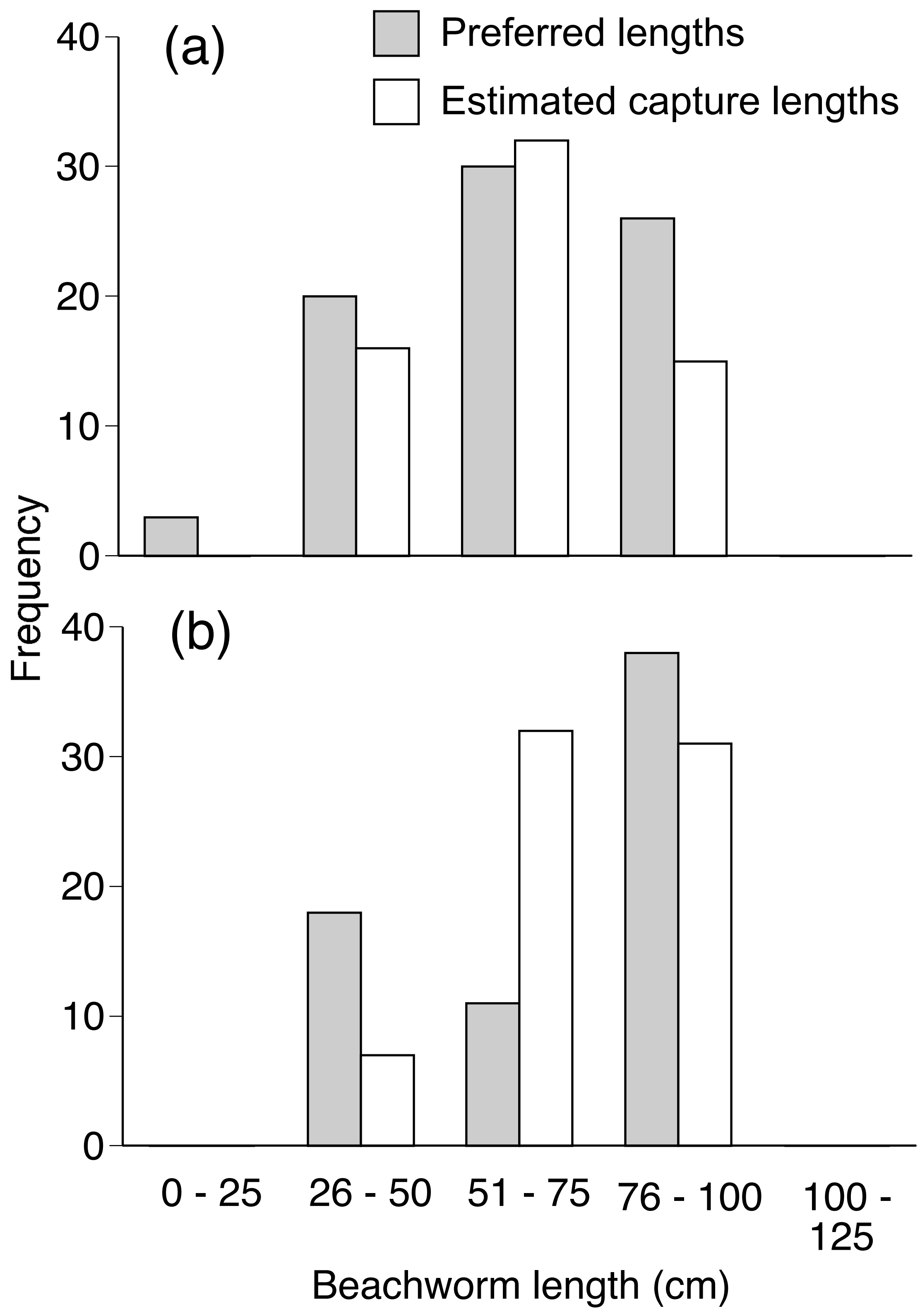

Figure 2.6: Frequency that fishers indicated a preference for beachworms of different lengths and the frequency that they captured beachworms of different lengths for use in fishing trips in (a) 2000 - n=79 preferred, n=64 captured and (b) 2001 - n=121 preferred, n=69 collected.

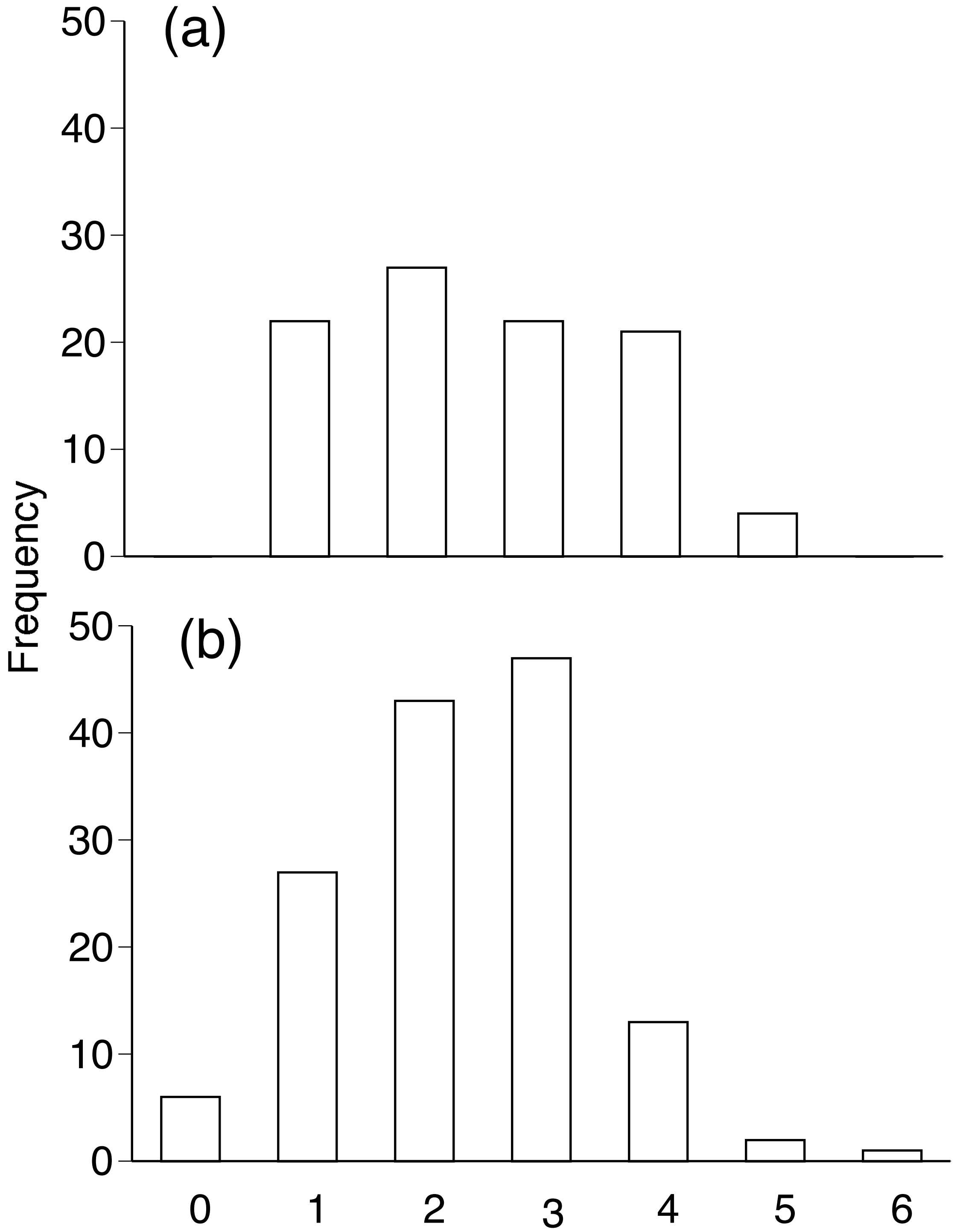

Figure 2.7: Frequency that fishers used different numbers of types of bait when fishing in (a) 2000 (n=96) and (b) 2001 (n=133)

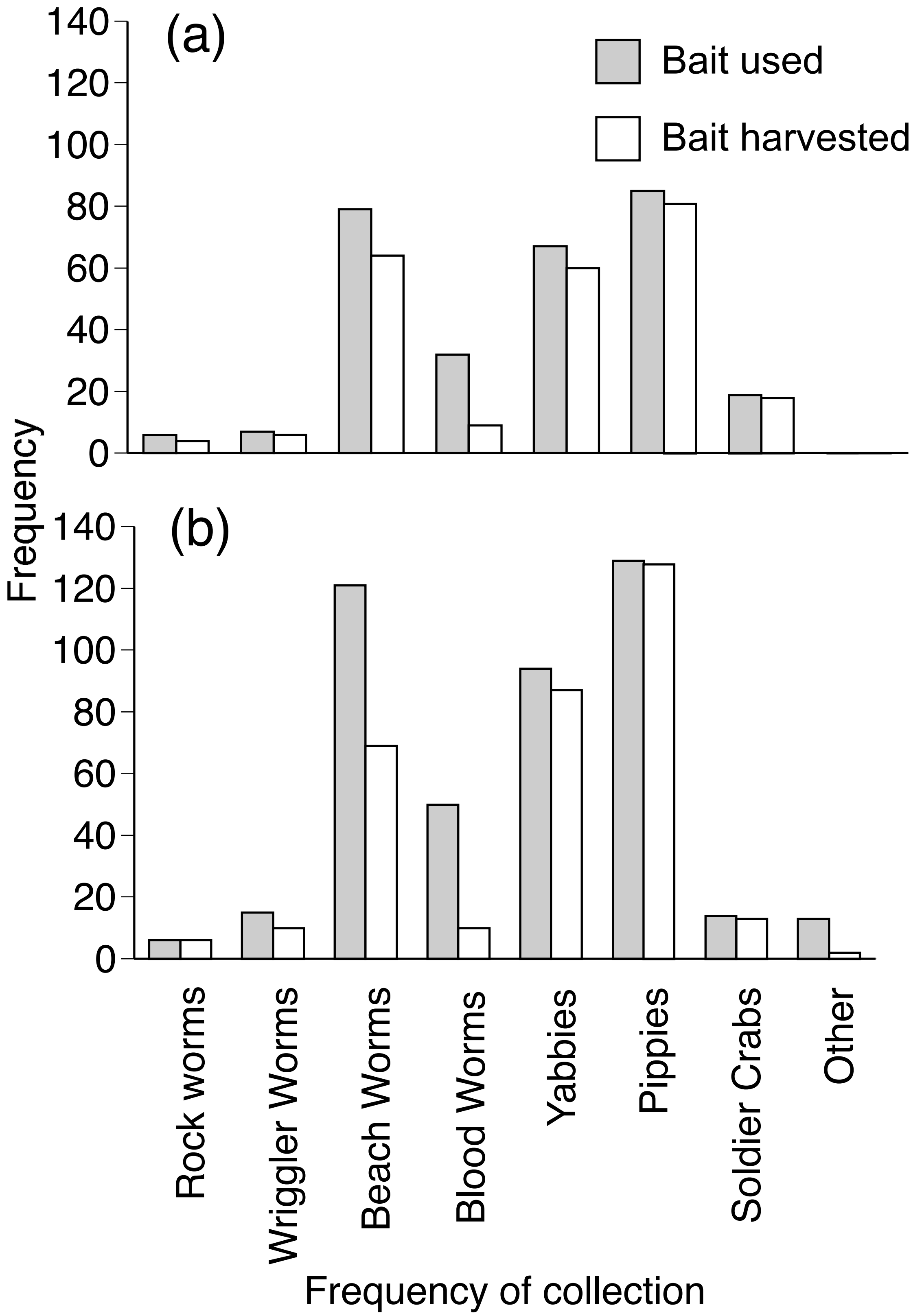

Figure 2.8: Frequency that fishers used different types of bait and the frequency that they harvested different types of bait when fishing in (a) 2000 (n=96) and (b) 2001 (n=133). Note that the fishers surveyed were not necessarily those who were collecting beachworms at the time the survey was done (compare with Figure 2.9).

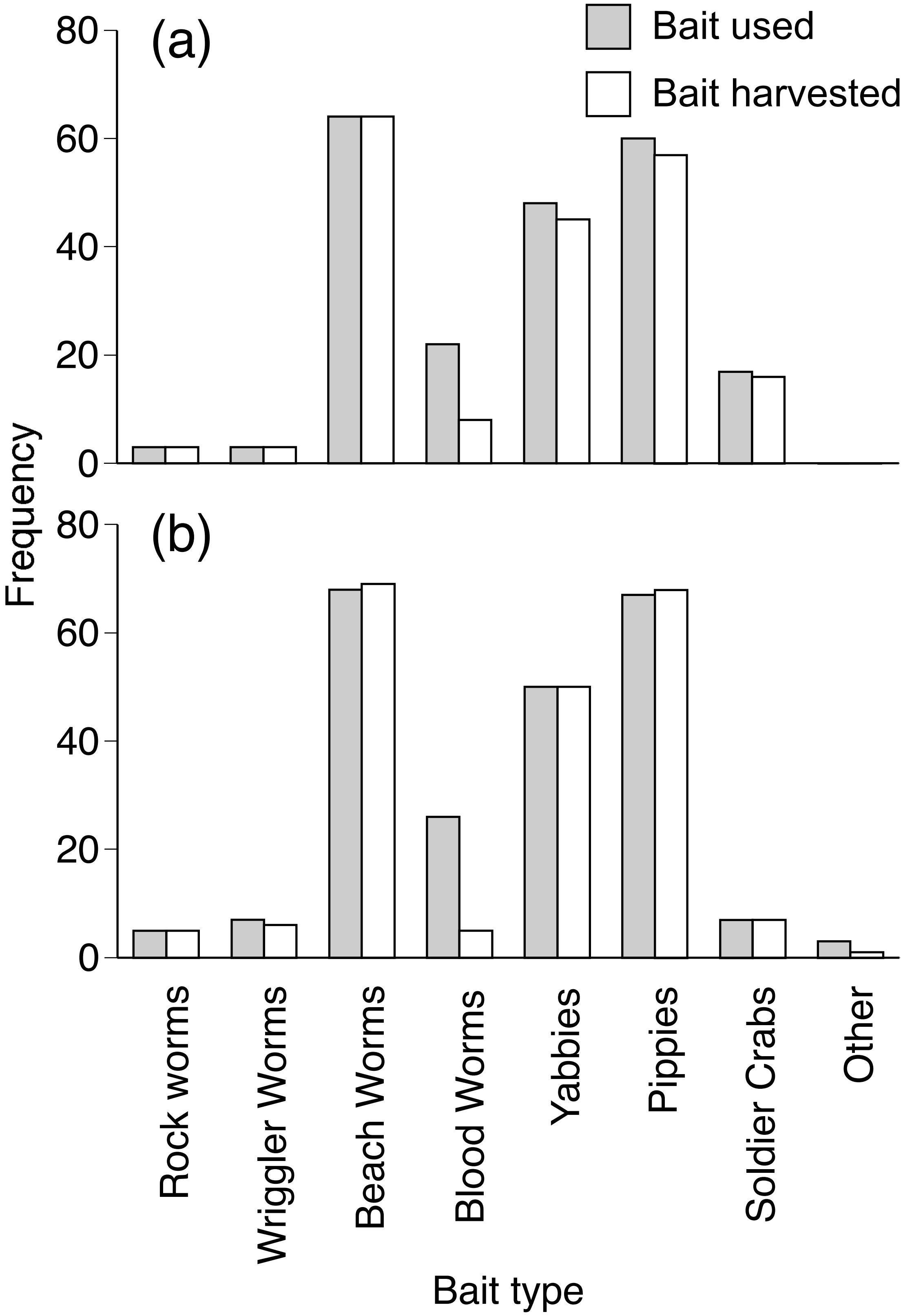

Figure 2.9: Frequency that fishers who were harvesting beachworms at the time the survey was administered used different types of bait and the frequency that they harvested different types of bait when fishing in (a) 2000 (n=96) and (b) 2001 (n=133).

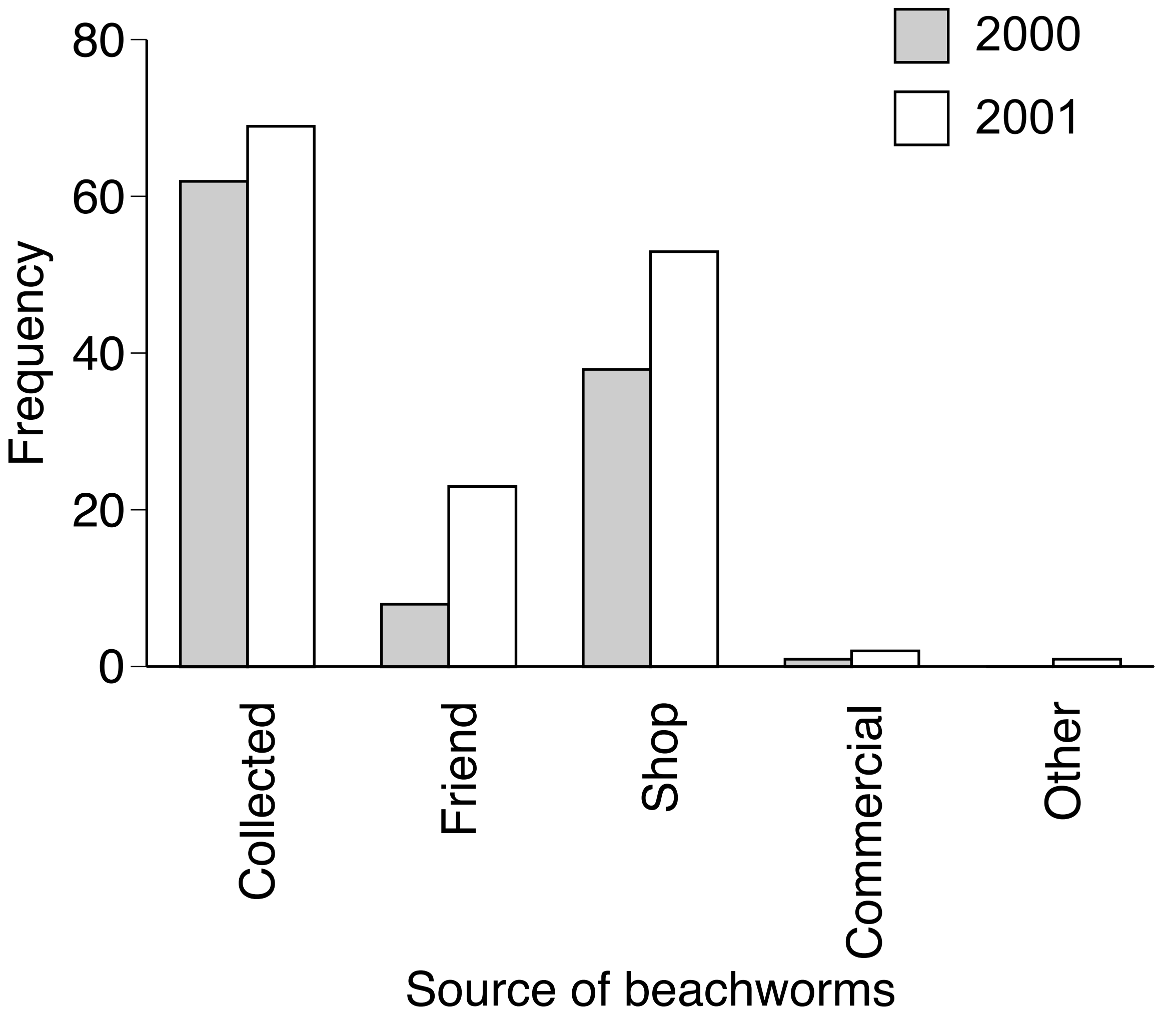

Figure 2.10: Frequency that fishers obtained beachworms from different sources when fishing in (a) 2000 (n=79) and (b) 2001 (n=121).

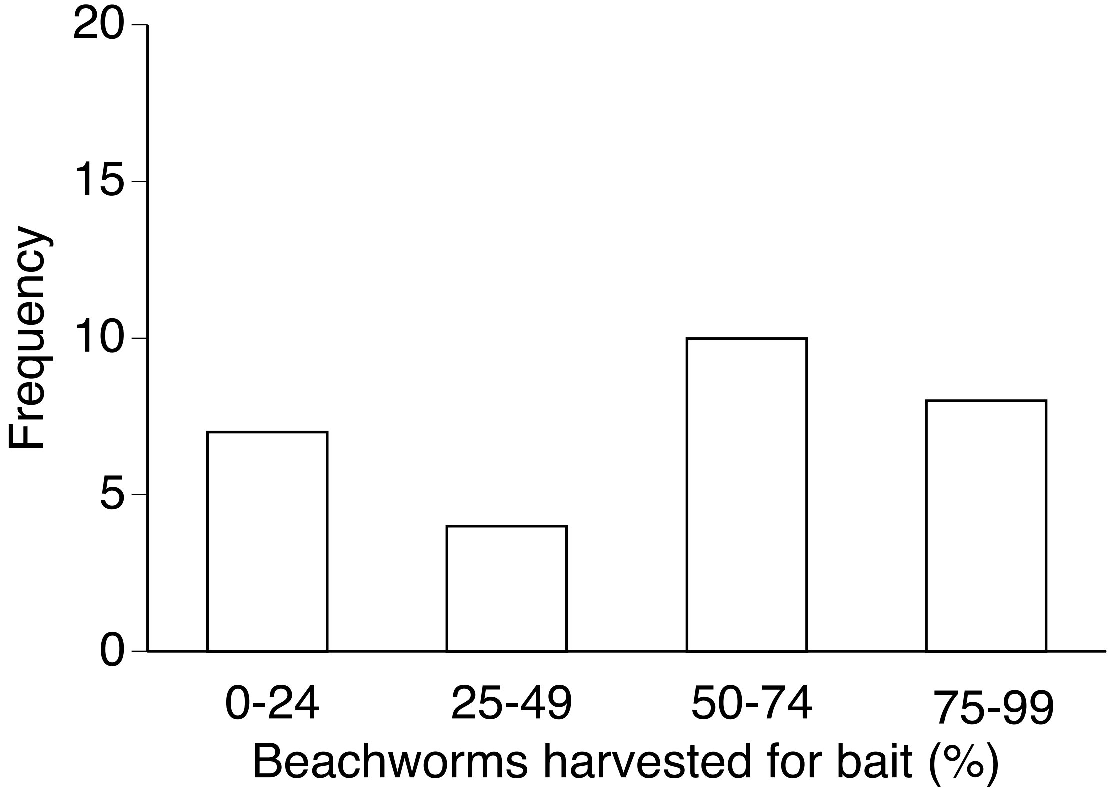

Figure 2.11: Frequency that fishers harvested different proportions of the bait that they used when fishing in 2000. This information was not available for 2001.

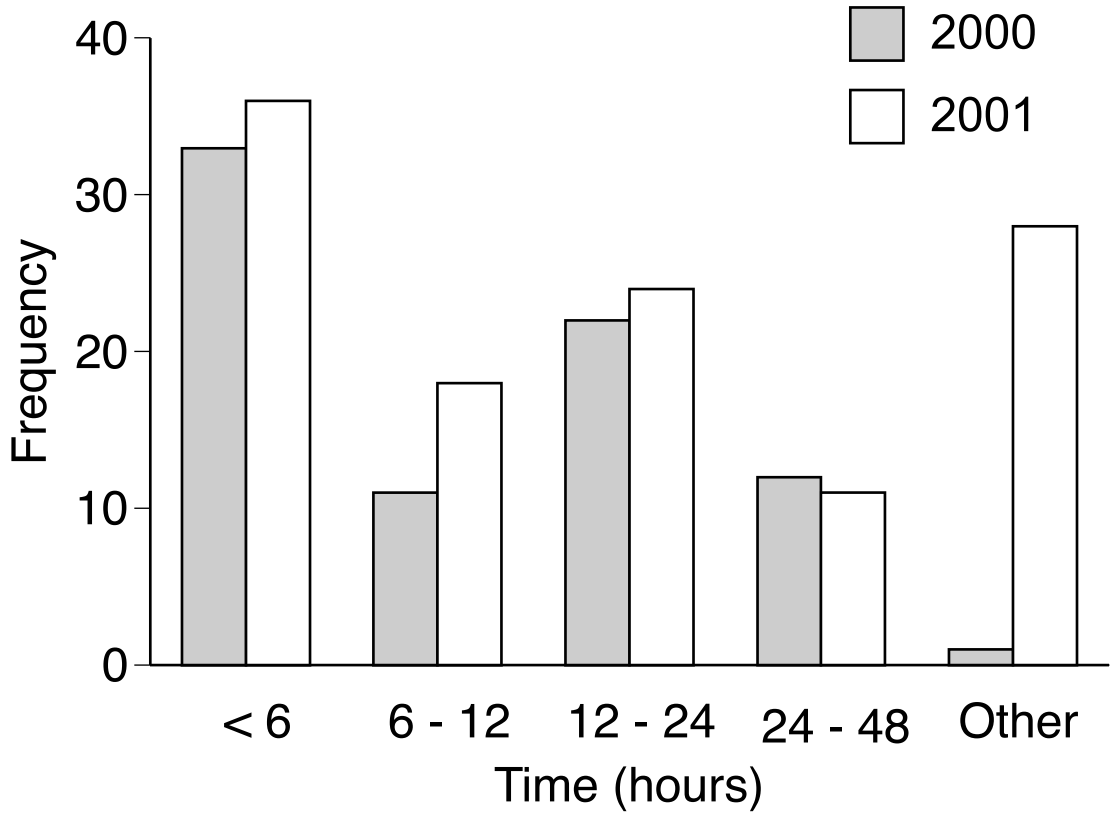

Figure 2.12: Frequency that fishers left beachworms for different amounts of time after harvesting the worms before these worms were used in a fishing trip

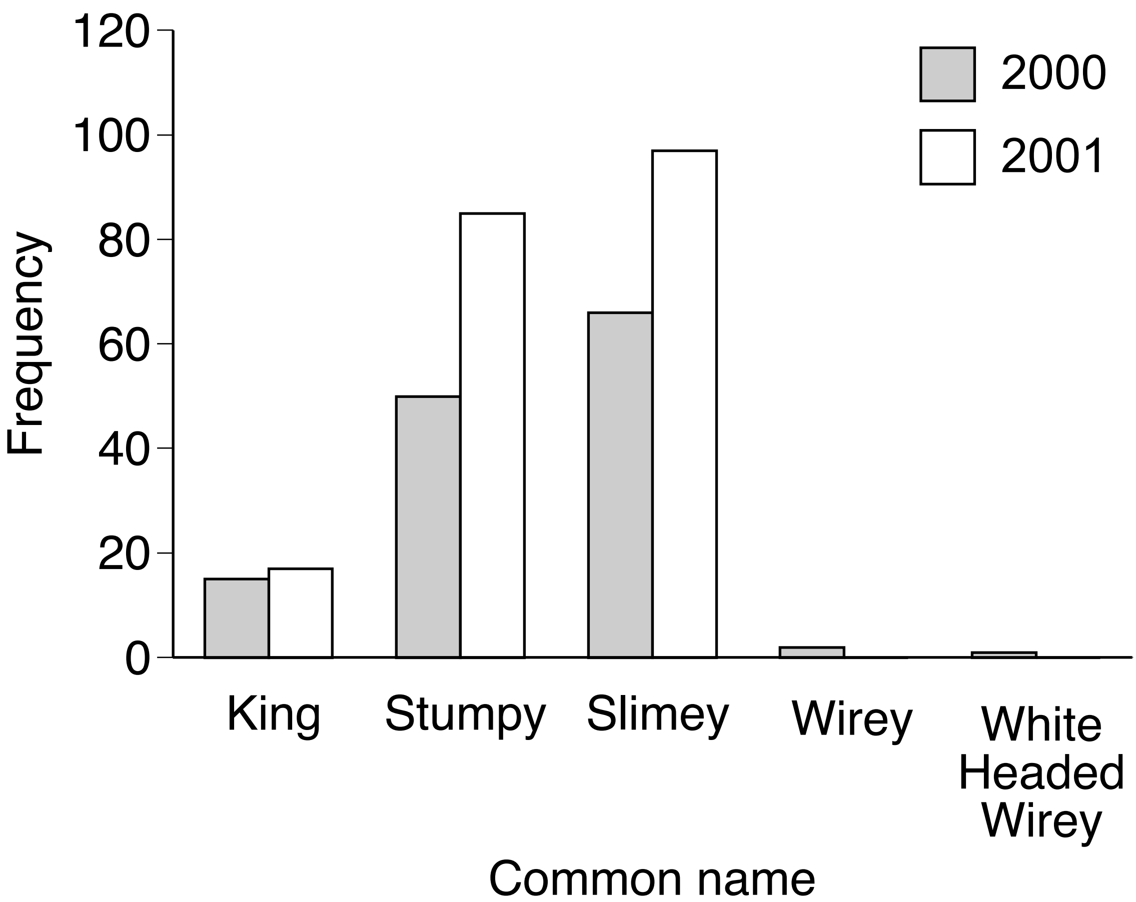

Figure 2.13: Frequency that fishers used the different species of beachworms as bait in 2000 (n=79) and 2001 (n=121).

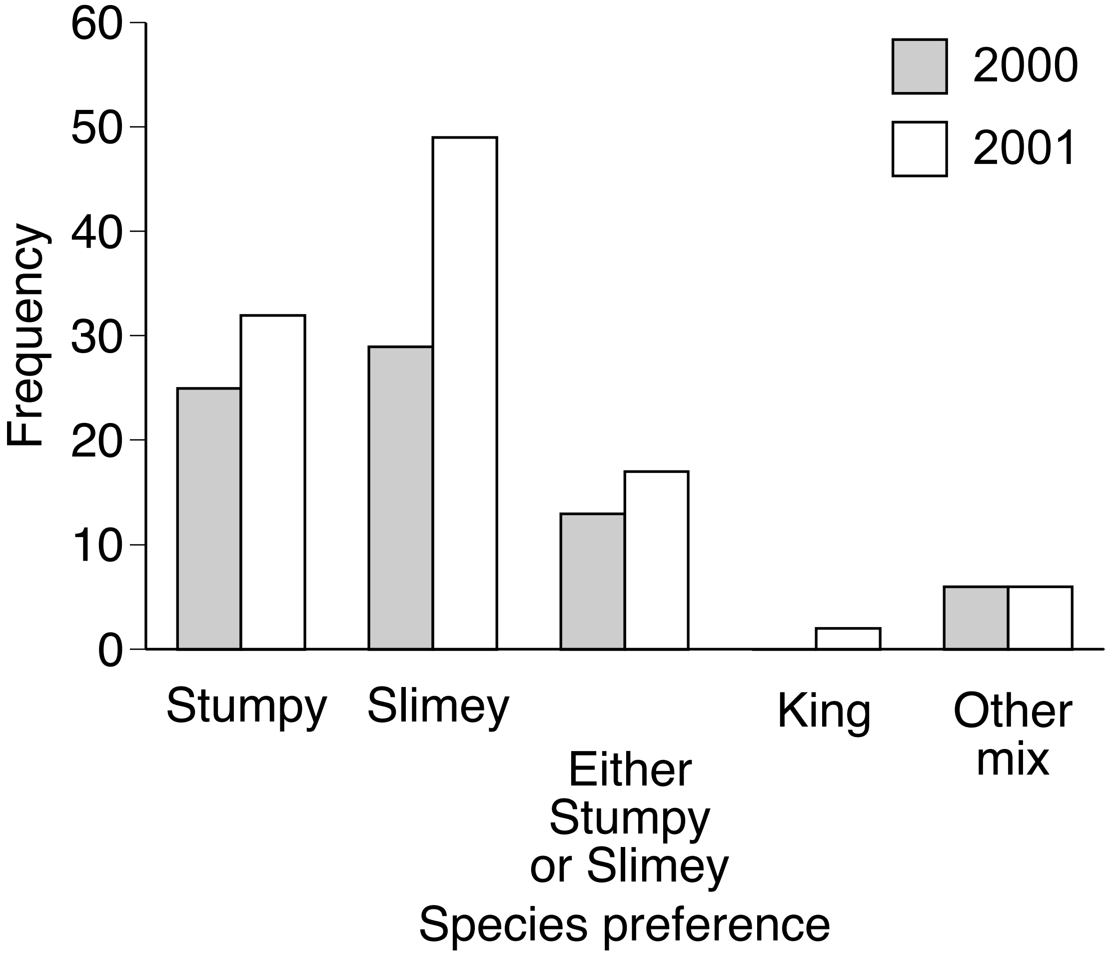

Figure 2.14: Frequency that fishers preferred a particular species of beachworm for use in a fishing trip in 2000 (n=79) and 2001 (n=121).

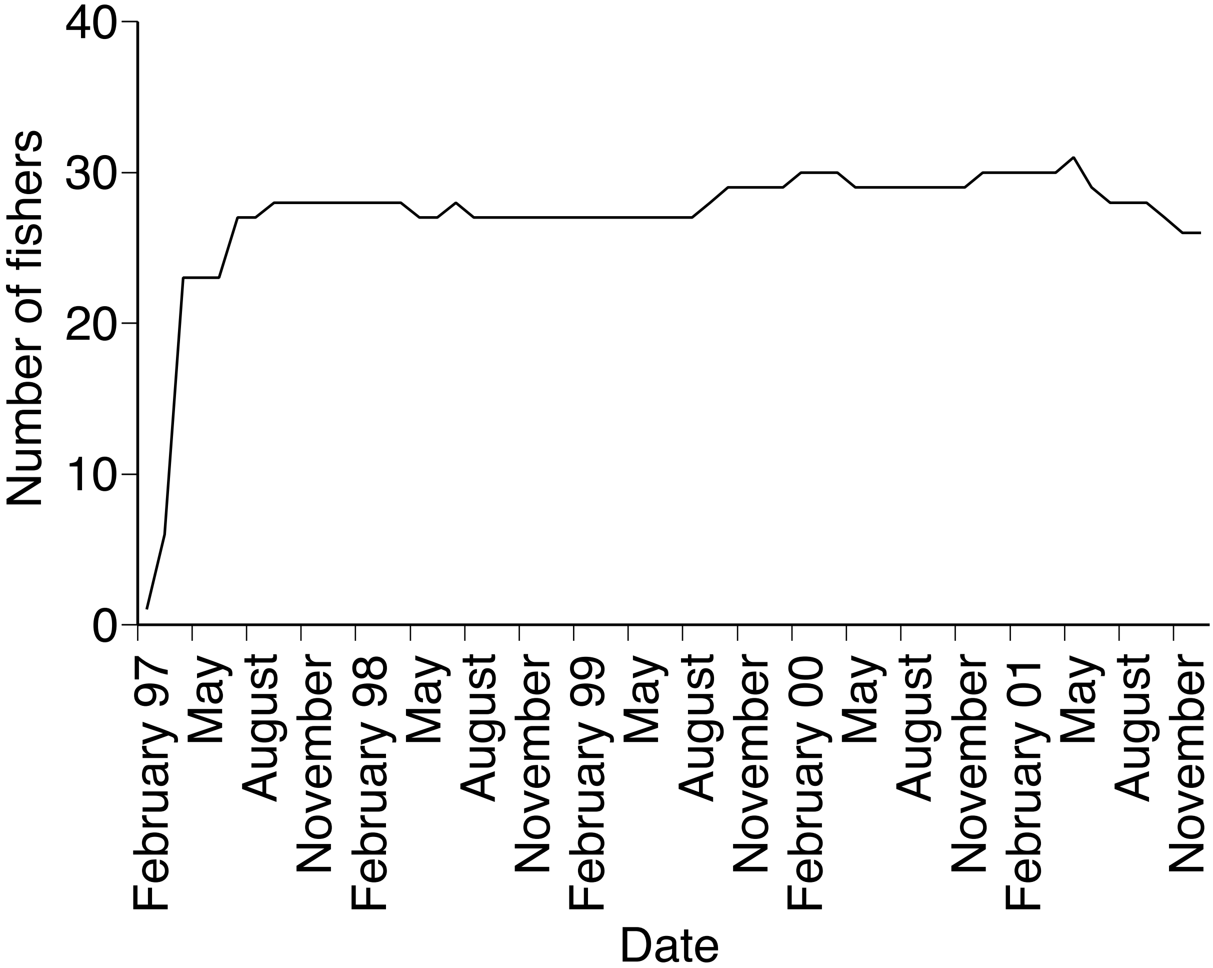

Figure 2.15: Number of licensed fishers participating in the Queensland commercial beachworm fishery, based on log-book data from February 1997 (when logbook monitoring began) to December 2001.

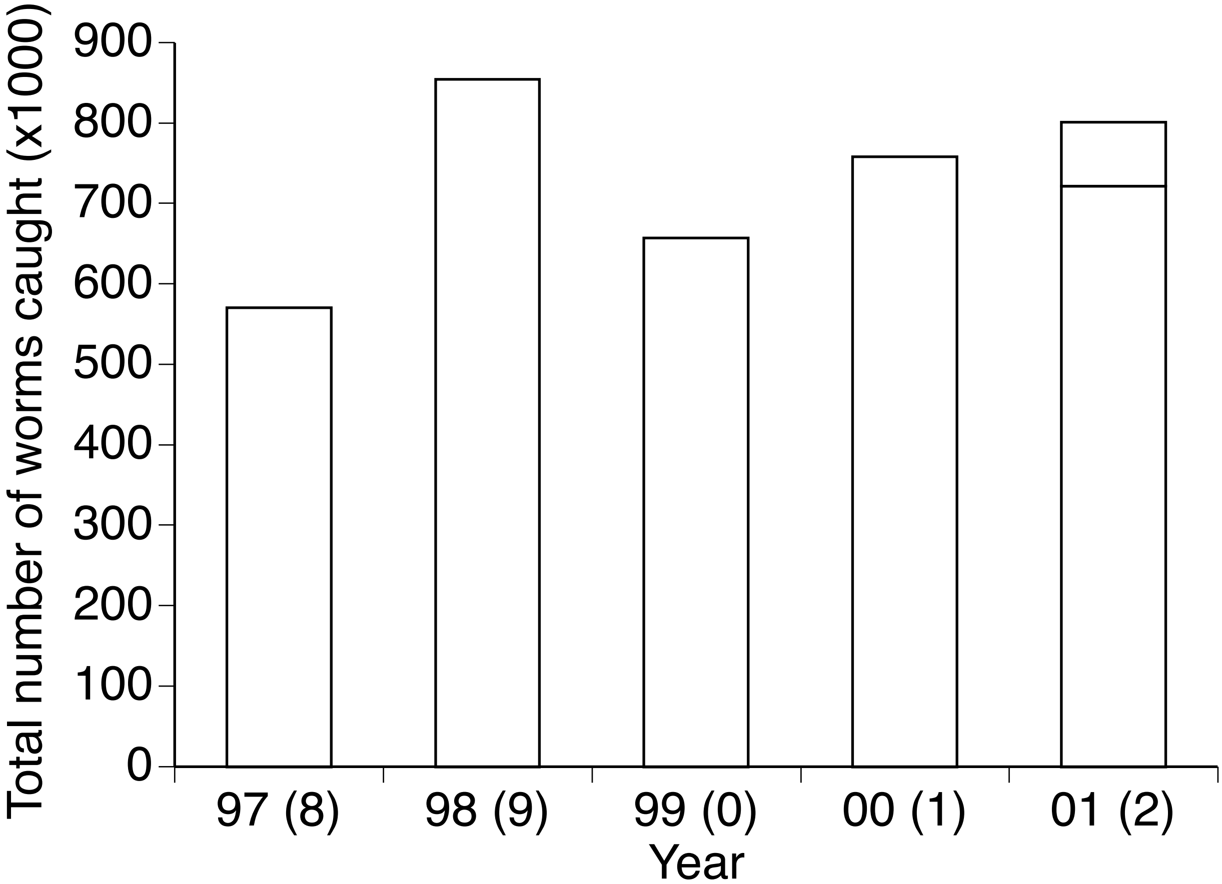

Figure 2.16: Total catch of beachworms for the Queensland commercial beachworm fishery for the period 1997/98 to 2001/02. Data were only available for 11 months in the 2001/02 block, so an estimate for January was based on the average for that month for all other years.

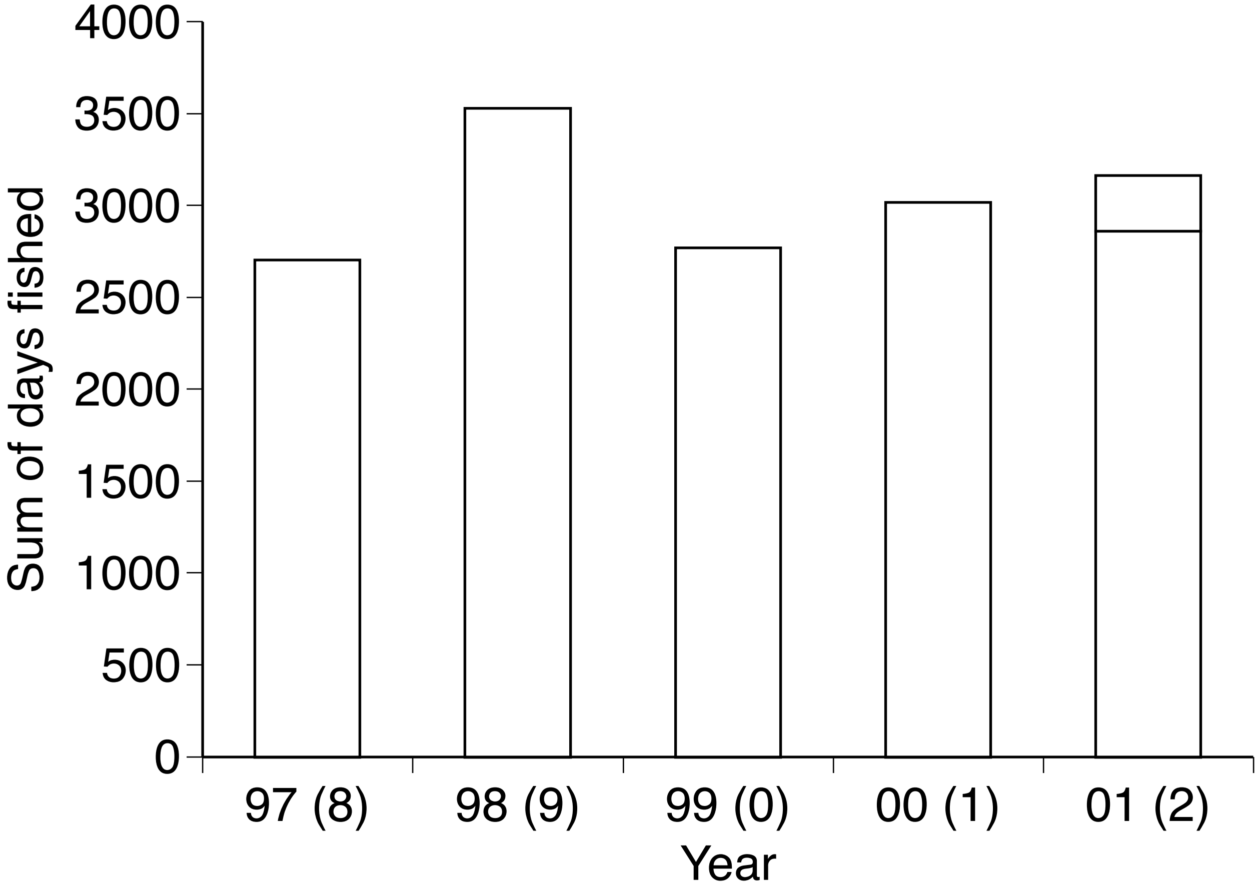

Figure 2.17: Total number of days fished in the Queensland commercial beachworm fishery for the period 1997/98 to 2001/02. Data were only available for 11 months in the 2001/02 block, so an estimate for January was based on the average for that month for all other years.

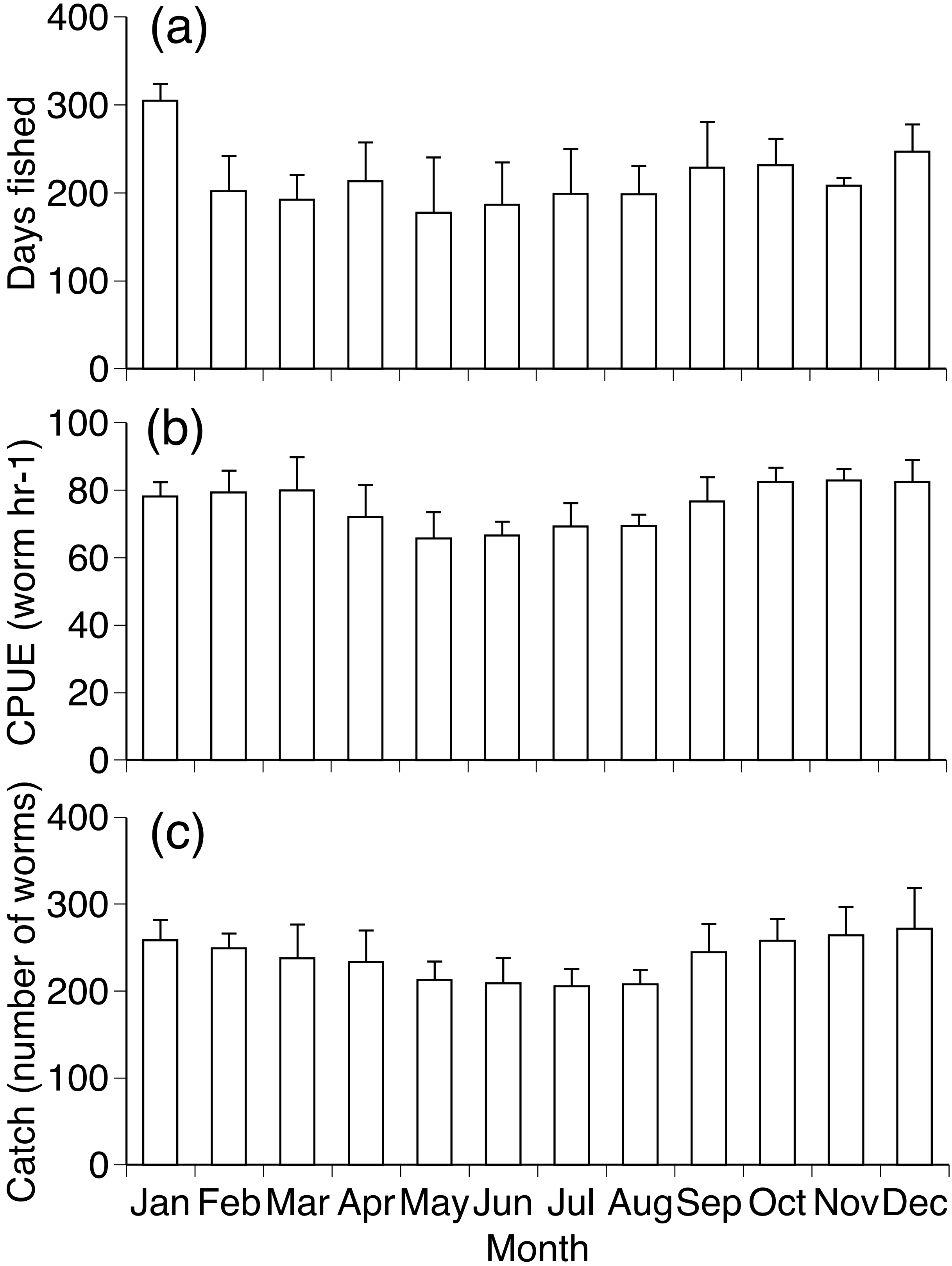

Figure 2.18: Comparison of monthly data for the Queensland commercial beachworm fishery, for the period 1997/98 to 2001/02. (a) average number of days fished, (b) average catch per unit effort and (c) average total catch (error bars are SD).

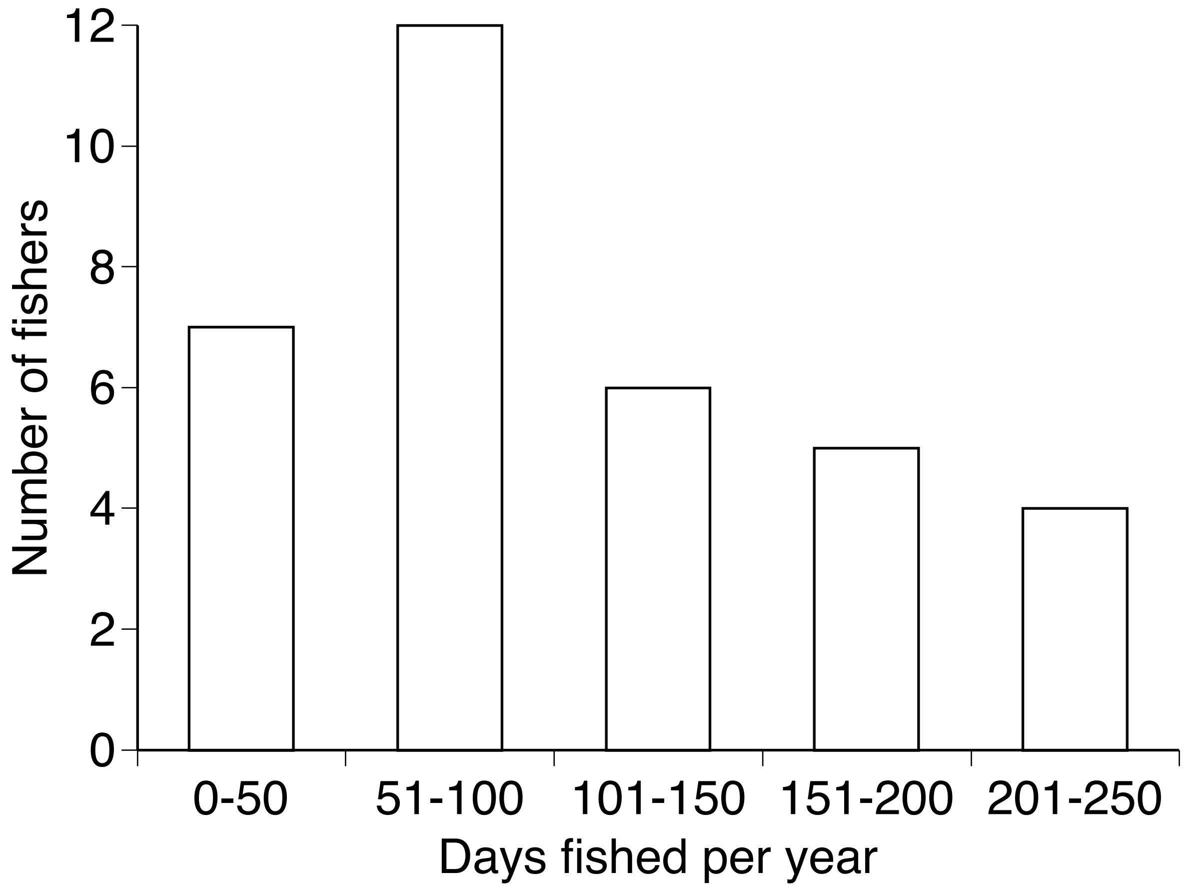

Figure 2.19: Number of commercial operators fishing for different numbers of days each year, averaged across the period from February 1997 to December 2001.

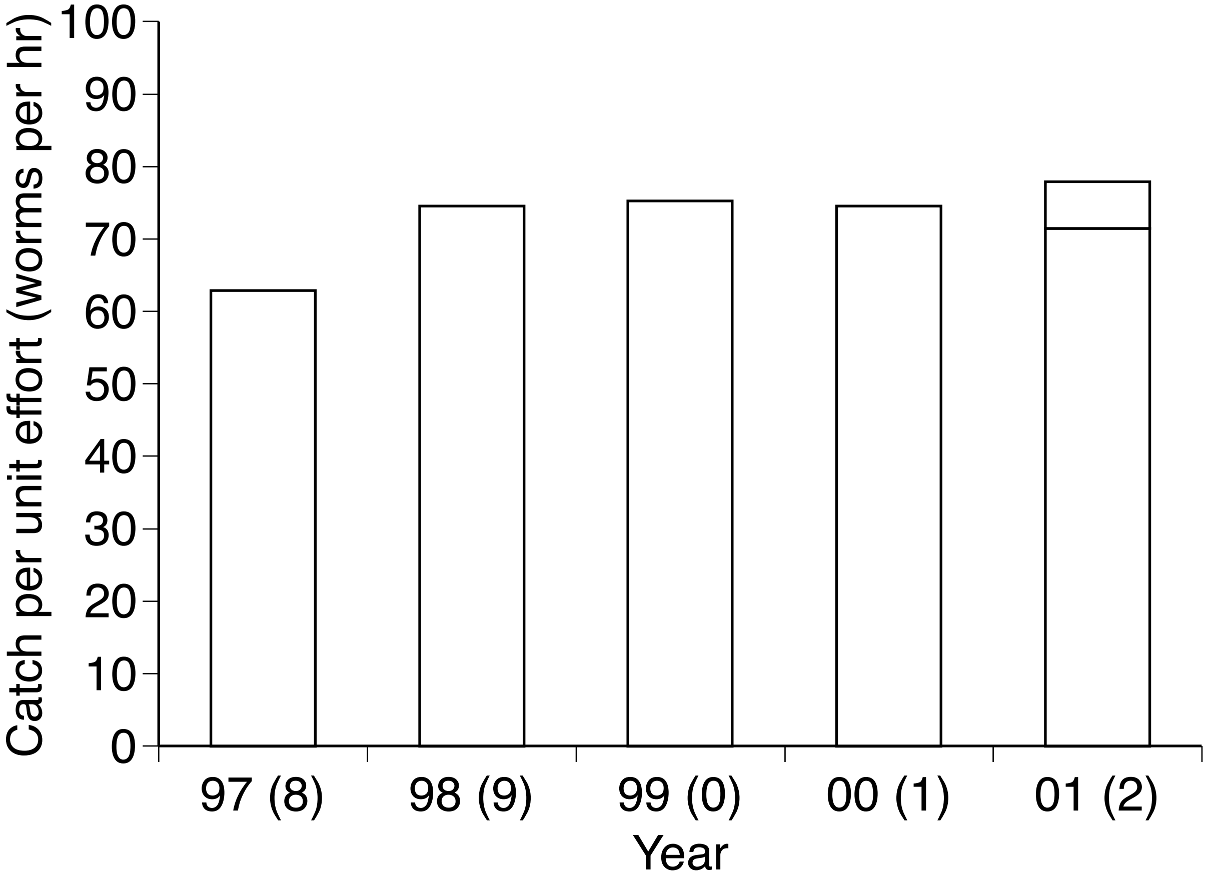

Figure 2.20: Catch per unit effort (worms per hour) for the Queensland commercial bachworm fishery, based on logbook data for the period 1997/98 to 2001/02. Data were only available for 11 months in the 2001/02 block, so an estimate forJanuary was based on the average for that month for all other years.

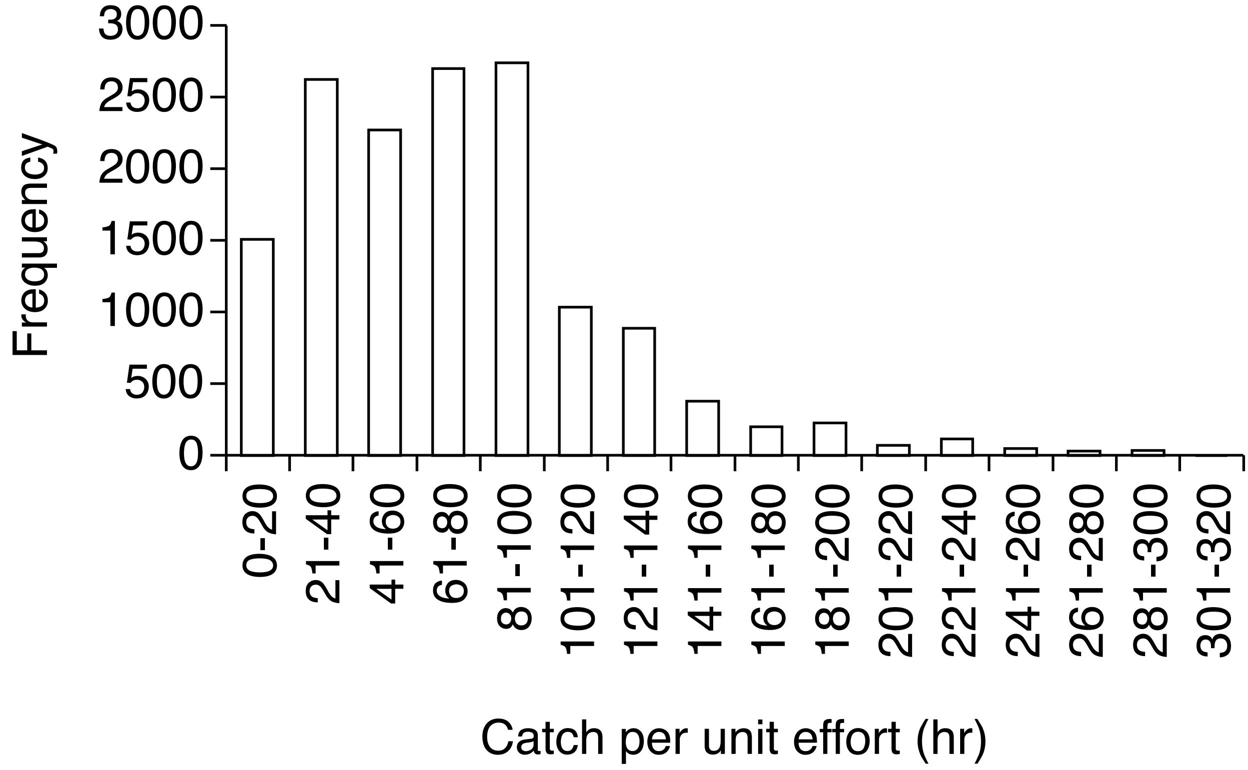

Figure 2.21: Frequency distribution of the number of fisher-days that resulted in different levels of catch per unit effort (worms caught per hour)

Chapter 3: Spatial and temporal distribution of beachworm densities

3.1 Introduction

The aim of this part of the study was to describe the patterns of spatial and/or temporal variation for beachworm populations in SE Queensland. This objective was investigated through sampling over a period of approximately 18 months, on a beach popular with recreational fishers and also accessed by commercial operators on a regular basis. Additional information was obtained on the physical characteristics (sediment grain size) of the beach environment at different heights.

3.2 Methods

3.2.1 Study Site

Sampling of beachworms was done on Teewah-Cooloola beach, on the south-eastern coast of Queensland, south of Fraser Island. Teewah-Cooloola beach is known to have a large beachworm population, that supports a local recreational beachworm fishery. In addition, the largest number of commercial beachworm fisherman work on Teewah-Cooloola beach, compared with other Queensland beaches (QFS log-book data). The beach is 47 km long, extending north from Noosa Heads to Double Island Point. The beach is characterized as a transverse rip and bar system with a low tide terrace, defined by offshore sandbars within 50 m of the intertidal zone and rip channels that are on average 200 m apart. Teewah-Cooloola beach is classified morphologically as an intermediate beach state (Short and Wright, 1983), with a mean wave height of 1.5 m, a mean wave period of 10s and a spring tide range > 2 m (exposing up to 75 m of intertidal sandy beach).

3.2.2 Estimating the abundance of beachworms

Sampling was not done within 10 km of Noosa Heads because this part of the beach has a gentle slope with no large frontal dunes, relatively little wave activity (due to the shelter provided by Noosa Heads) and a very small swash zone. All these factors create an unsuitable habitat for beachworms. Three geographically separate study sites were sampled along the remainder of the beach. The first site was located 14 km north from Noosa Heads, approximately 3 km away from the start of a series of large frontal dunes, at a point where wave activity on the beach started to increase. The second site was located midway along the beach, 23.5 km north from Noosa Heads. The third sample site was located at the end of the beach next to the protected headland, 3 km from Double Island Point. The last vehicle access point onto the beach was slightly south of this third site. This meant the third site had noticeably less 4WD traffic passing along the shoreline than the other sites.

At each site, three tidal heights on the beach were sampled, hereafter referred to as high, mid, and low zones. Preliminary field sampling had shown that beachworms were only found on the beach cusps and could only be sampled in the wet sand, approximately four hours before low tide. The high tide point of the previous tide was marked around six hours before the next predicted low tide based on observations of the wash markings and wrack line. Four hours prior to low tide, the upper extent of 10 successive waves was recorded and the median position of these waves was used to describe the high tide zone. At this beach height, a central sampling station of was marked. On either side of this central station, an additional 7 stations, 10 m apart, were marked for a total of 15 sampling stations at each height.

At each station, two, 1 x 1 m raised, adjacent quadrats were positioned approximately 0.5 m above the substratum. Earlier pilot studies showed that the presence of the presence of the quadrats had no effect on the rate of appearance of beachworms. The quadrats were left unattended for 5 minutes (in practice the time taken to set up all quadrats), then burley was washed through the receding swash above each sampling station (pair of quadrats) for a time period equivalent to five waves. During this time, the number of beachworms emerging from the sand within each of the quadrats was recorded. For analyses, the number emerging within the two quadrats was summed to provide an estimated density per 2 m^2.

This methodology was repeated for the mid and low tide zones in turn. The mid-tidal zone was sampled approximately 2 hours before predicted low tide and the low tide zone about 0.5 hr before predicted low tide (the minimal time required for all sampling to be conducted). Adverse weather conditions prevented some sites from being sampled on many occasions. This happened most often for the low zone, where high wave activity frequently made sampling impossible.

Sampling of the three study sites was carried out sporadically (approximately every one to two months) between April 2000 and October 2001 (inclusive). Each sampling site was accessed in a 4WD vehicle and located by the distance driven along the beach and by local physical landmarks. The sampling site was taken as the closest beach cusp to the site location. Each sampling trip was conducted over a three day period during new moon, to minimise the effects of tidal variation on comparative monthly observations. During a new moon period the tidal range is the greatest, with the highest high tides, and lowest low tides. During the time sampling was being done at each site, the number of 4WD vehicles that passed the sampling station was recorded.

3.2.3 Sediment grain-size analysis

A single core of sediment was collected at each height in order to determine the characteristics of the sediments (grain size) at the different sites along the beach. The core was taken to 0.7 m depth, and 0.1 m sections were placed in appropriately labelled bags. During 2001, a measure of sediment compaction (penetrability) was taken by dropping a rod (of standard weight) into the sand and measuring (in mm) how far it penetrated the sand. The number of 4WD vehicles driving past every site during the entire sampling time was also recorded.

Each section of each core was dried to constant weight at 65 °C. The sand sample was then divided using a sediment sample divider and 50 % of the sample was placed into nested sieves (4000, 2000, 1000, 500, 250, 125, and 62 μm) to allow the grain size distribution to be determined. Mean grain-size (phi) and sorting coefficient was determined using the Method of Moments (Folk, 1980).

3.3 Results

The amount of data collected on the abundance of beachworms varied considerably among the three sites: Site 1 (n = 36 height x time combinations), followed by Site 3 (n = 23 height x time combinations), with the fewest records obtained from Site 2 (n = 16 height x time combinations). Due to the significant gaps in the data series (Figures 3.1, 3.2 and 3.3), resulting from the irregular sampling schedule, it was difficult to address specific questions about spatial and temporal variation in the abundance of the worms. Instead, the focus was on identifying trends where the dataset was more complete. The main periods in which data for consecutive months were available were: 04/00 - 11/00 and 01/01 - 04/01 for Site 1; 04/00 - 06/00 for Site 2; and 04/00 - 06/00 and 01/01-04 for Site 3.

At Site 1, the densities of beachworms varied considerably with the largest density in the high zone in July 2000 (mean density = 5.0 ± 2.2 m^{-2}) (Figure 3.1). Numbers then decreased over the following period, with no worms found in November 2000. Sampling in the mid zone, showed similar overall trends to the high zone except densities were initially larger in the mid-zone than the high zone (April 2000 - mean density = 3.3 ± 1.7 m^{-2}). The abundance in the mid-zone then peaked in June 2000 (mean density = 5.0 ± 1.0 m^{-2}) followed by a rapid decline in July to approximately half the density observed at the high zone in July 2000. Densities in the mid zone from November 2000 showed that beachworms were still found at this height on the beach compared with the pattern for the high zone. The data available for the low zone indicates consistently smaller densities in the month of May and from July 2000 to October 2000 (mean densities ranging from 1.1 ± 0.8 m^{-2} to 1.9 ± 0.5 m^{-2}). In November 2000, population densities increased by almost 150 % to 2.9 ± 1.0 m^{-2} over the lowest density seen in the months beforehand. From January 2001 to April 2001 (available for the high and mid zones only) beachworm densities were consistently low and did not vary between the two zones. There were only two more sampling occasions after April 2001. In August 2001, a large density of worms was recorded in the high zone (mean density = 4.7 ± 1.8 m^{-2} - just below the peak from the previous year) and a relatively large density in the mid zone (mean density = 3.2 ± 1.1 m^{-2}) was observed.

At Site 2, beachworm densities were greatest in May and June 2000 in the mid zone (mean density = 3.6 ± 0.5 m^{-2} and 3.5 ± 2.0 m^{-2} respectively) (Figure 3.2). Similar to Site 1, the abundance in the mid zone declined in August 2000. The densities of beachworms in the high zone were very small from May until July 2000 and then increased to the highest levels in August 2000 (mean density = 2.5 ± 0.8 m^{-2}). The mean density of worms the following August (2001) was only 1.4 ± 0.8 m^{-2}. In the high zone at Site 2, no worms were found in January and February 2001. In the mid zone, no worms were found in February 2001 while a small density was recorded (mean density = 1.3 ± 0.4 m^{-2}) in January 2001.

At Site 3, the largest densities of beachworms were found in May 2000 in the mid zone (mean density = 6.0 ± 0.7 m^{-2}) (Figure 3.3), but in all other months the densities of beachworms in the mid zone were very small (with a maximal mean density of 0.1 ± 0.2 m^{-2}). In the high zone, densities peaked in November 2000, January 2001 and March 2001 (with a mean density of ~ 3.0 m^{-2}). Even though large densities were observed in these months, numbers were not stable (see Figure 3.3) as considerably smaller densities were observed in February and April (mean density of ~ 0.8 m^{-2}). In the low zone, data were only available for three months (November 2000, January 2001 and August 2001) all of which had relatively small densities of beachworms (with mean densities < 1.3 m^{-2}).

Data on the number of 4WD vehicles passing the sampling sites, showed that a greater number of 4WDs passed by Site 1 compared with Site 2 (Figure 3.4). At Site 1, beach traffic was greatest in October and November 2000 followed by March and

August 2001. At Site 2, traffic was greatest in August 2000 and 2001 but was also quite high in January 2001. At Site 3, positioned northward of the last vehicular access point onto the beach, very little 4WD traffic was recorded, with the highest monthly record in February 2001.

Each sand core was split into seven 0.1 m sections and the sediment sections were analysed separately. These data are presented in Appendix 1, but only the average for each core was used in the final grain size analysis (Table 3.3). No replicate samples were collected for the different heights and sites, so no formal analysis could be done on these data, precluding any examination of temporal or spatial variation in the physical characteristics at each of the sites. All the sediments were poorly sorted (between 1.0 - 2.0 phi) (Figures 3.5, 3.6, 3.7; Table 3.3). Data on sediment penetrability was only collected in 2001 (Table 3.4, Figure 3.8) but again, a lack of appropriate replication prevented any formal analysis or interpretation of these data.

3.4 Discussion

The large variation in the frequency that each of the three sites was sampled precluded any firm conclusions being drawn from the available data. Examination of the major trends in the densities of the beachworms and patterns of their distribution among the three tidal heights, suggested there were similar patterns at Sites 1 and 2, but these were different for Site 3. Similarly, the sampling design for description of the physical characteristics of the beach (grain size analysis and penetrability measures) provided too few data to allow any formal analysis and also prevented any attempts to correlate the patterns of distribution of the beachworms with the physical characteristics on the beach.

Beachworm densities were generally greater at Site 1 than at Site 2 at all three tidal zones. These variations may have been due to differences in the nature of the swash climate between the two sampled sites. It has already been suggested that macrofauna species richness, abundance and biomass increases from reflective to dissipative beaches (Jaramillo and McLachlan, 1993; Jaramillo et al., 1998). Unfortunately, no data were collected that would allow the different sites to be categorised in relation to their broad exposure characteristics.

Densities of beachworms at Sites 1 and 2 indicated that the largest densities occurred in the high and mid zones, in June and/or July in 2000 and in August 2001, suggesting there may be a seasonal cycle in the abundance of the worms, with a peak in winter. It is also possible that the increase in densities occurring in the high zone lagged slightly behind the mid zone in 2000 and this may be linked to differences in the relative environmental harshness of the habitats in which the worms occurred. Initially, greater densities may occur in the mid zone because worms are better protected from harsher terrestrial environmental conditions, than in the exposed high tidal zone (i.e. temperatures in the high tidal zone may be warmer in the early months of winter). By November 2000, densities at Site 1 had decreased dramatically in the high and mid zone, while at Site 2, very small densities were found in the high and mid zone in January and February 2001. The decrease in the abundance of worms around November may be explained by beach living conditions being less favourable to worms in late winter/early spring, and it appears that environmental conditions in the high zone might be harsher than in the mid zone, reflected by the greater absence of worms there. The patterns of abundance at Site 3 appeared to be different from the other sites suggesting that different physical conditions at this site provide a less suitable habitat for the worms.

Table 3.1. Frequency with which data were collected between April 2000 and August 2001 at each of the three heights at the three sites (√ = data available, _ = no data available).

Sample date		Site 1			Site 2			Site 3			*Total number of samples*
		High	Mid	Low	High	Mid	Low	High	Mid	Low	
2000	April	√	√	_	√	√	_	√	√	_	6
	May	√	√	√	√	√	_	√	√	_	7
	June	√	√	_	√	√	_	√	√	_	6
	July	√	√	√	_	_	_	_	_	_	3
	August	√	√	_	√	√	_	√	_	_	5
	September	√	√	√	√	√	_	√	√	_	7
	October	√	√	√	_	_	_	_	_	_	3
	November	√	√	√	_	_	_	√	√	√	6
	December	_	_	_	_	_	_	_	_	_	0
2001	January	√	√	√	√	√	√	√	√	√	9
	February	√	√	_	√	√	_	√	√	_	6
	March	√	√	_	_	_	_	√	√	_	4
	April	√	√	_	_	_	_	√	√	_	4
	May	_	_	_	_	_	_	_	_	_	0
	June	√	√	√	_	_	_	_	_	_	3
	July	_	_	_	_	_	_	_	_	_	0
	August	√	√	√	√	√	√	_	√	√	8
Total number of samples		14	14	8	8	8	2	10	10	3	

Table 3.2. Frequency with which samples were collected for analysis of sediment grain size between April 2000 and August 2001 (√ = data available, _ = no data available. No replicate samples were collected on any occasion.

Sample date		Site 1			Site 2			Site 3			*Total number of samples*
		High	Mid	Low	High	Mid	Low	High	Mid	Low	
2000	April	√	√	√	√	√	√	_	_	_	*6*
	May	√	√	√	√	√	_	√	√	_	*7*
	June	√	√	_	√	√	_	√	√	_	*6*
	July	√	√	√	_	_	_	_	_	_	*3*
	August	√	√	√	√	√	√	_	_	_	*6*
	September	√	√	√	√	√	_	√	√	_	*7*
	October	√	√	√	_	_	_	_	_	_	*3*
	November	√	√	√	_	_	_	√	√	√	*6*
	December	_	_	_	_	_	_	_	_	_	*0*
2001	January	√	√	√	√	√	√	√	√	√	*9*
	February	√	√	_	√	√	_	√	√	_	*6*
	March	√	√	_	_	_	_	√	√	_	*4*
	April	√	√	_	_	_	_	√	√	_	*4*
	May	_	_	_	_	_	_	_	_	_	*0*
	June	√	√	√	_	_	_	_	_	_	*3*
	July	_	_	_	_	_	_	_	_	_	*0*
	August	√	√	√	√	√	√	√	√	√	*9*
Total number of samples		*14*	*14*	*10*	*8*	*8*	*4*	*9*	*9*	*3*	

Table 3.3. Mean grain size (phi) and sorting coefficient of the sediments collected between April 2000 and August 2001. Values are from a single sediment core collected on each occasion at each of the heights for which values are shown.

Sample date		Site 1			Site 2			Site 3		
		High	Mid	Low	High	Mid	Low	High	Mid	Low
2000	April	1.83ϕ	1.65ϕ	1.66ϕ	1.62ϕ	1.75ϕ	1.59ϕ	–	–	
		0.68	0.52	0.62	0.42	0.51	0.56			
	May	1.79ϕ	1.51ϕ	1.67ϕ	1.47ϕ	1.58ϕ		1.55ϕ	1.68ϕ	
		0.54	0.70	0.63	0.58	0.59		0.51	0.46	
	June	1.78ϕ	1.61ϕ		1.74ϕ	1.62ϕ		1.64ϕ	1.57ϕ	
		0.54	0.65		0.48	0.49		0.43	0.42	
	July	1.98ϕ	1.89ϕ	1.86ϕ						
		0.53	0.56	0.55						
	August	1.57ϕ	1.65ϕ	1.58ϕ	1.56ϕ	1.76ϕ	1.93ϕ			
		0.70	0.70	0.79	0.65	0.68	0.56			
	September	1.52ϕ	1.76ϕ	2.09ϕ	1.68ϕ	1.71ϕ		1.74ϕ	1.71ϕ	
		0.83	0.74	0.61	0.55	0.57		0.53	0.52	
	October	1.61ϕ	1.67ϕ	1.58ϕ						
		0.71	0.75	0.72						
	November	1.84ϕ	1.71ϕ	1.78ϕ				1.66ϕ	1.64ϕ	1.64ϕ
		0.59	0.62	0.59				0.45	0.47	0.45
	December									
2001	January	2.14ϕ	1.73ϕ	1.45ϕ	1.98ϕ	1.72ϕ	1.50ϕ	1.78ϕ	1.72ϕ	1.60ϕ
		0.50	0.53	0.66	0.46	0.48	0.45	0.49	0.46	0.40
	February	1.71ϕ	1.32ϕ		1.77ϕ	1.66ϕ		1.71ϕ	1.70ϕ	
		0.72	0.81		0.65	0.72		0.57	0.66	
	March	1.69ϕ	1.65ϕ					1.88ϕ	1.71ϕ	
		0.54	0.52					0.51	0.50	
	April	1.69ϕ	1.68ϕ					1.77ϕ	1.74ϕ	
		0.58	0.59					0.51	0.48	
	May									
	June	1.93ϕ	1.67ϕ	1.55ϕ						
		0.61	0.61	0.78						
	July									
	August	1.95ϕ	1.90ϕ	1.79ϕ	1.86ϕ	1.83ϕ	1.86ϕ	1.59ϕ	1.68ϕ	1.63ϕ
		0.57	0.62	0.65	0.55	0.53	0.55	0.40	0.48	0.48

Table 3.4: Frequency with which sediment compaction (penetrability) data were collected between January 2001 and August 2001 (√ = data available, _ = no data available).

Sample date		Site 1			Site 2			Site 3			*Total number of samples*
		High	Mid	Low	High	Mid	Low	High	Mid	Low	
2001	January	_	_	_	√	√	√	√	_	_	*4*
	February	√	√	_	√	√	_	√	√	_	*6*
	March	√	√	_	_	_	_	√	√	_	*4*
	April	√	√	_	_	_	_	√	√	_	*4*
	May	_	_	_	_	_	_	_	_	_	*0*
	June	_	_	_	_	_	_	_	_	_	*0*
	July	_	_	_	_	_	_	_	_	_	*0*
	August	√	√	_	√	√	_	_	√	√	*6*
Total number of samples		*4*	*4*	*0*	*3*	*3*	*1*	*4*	*4*	*1*	

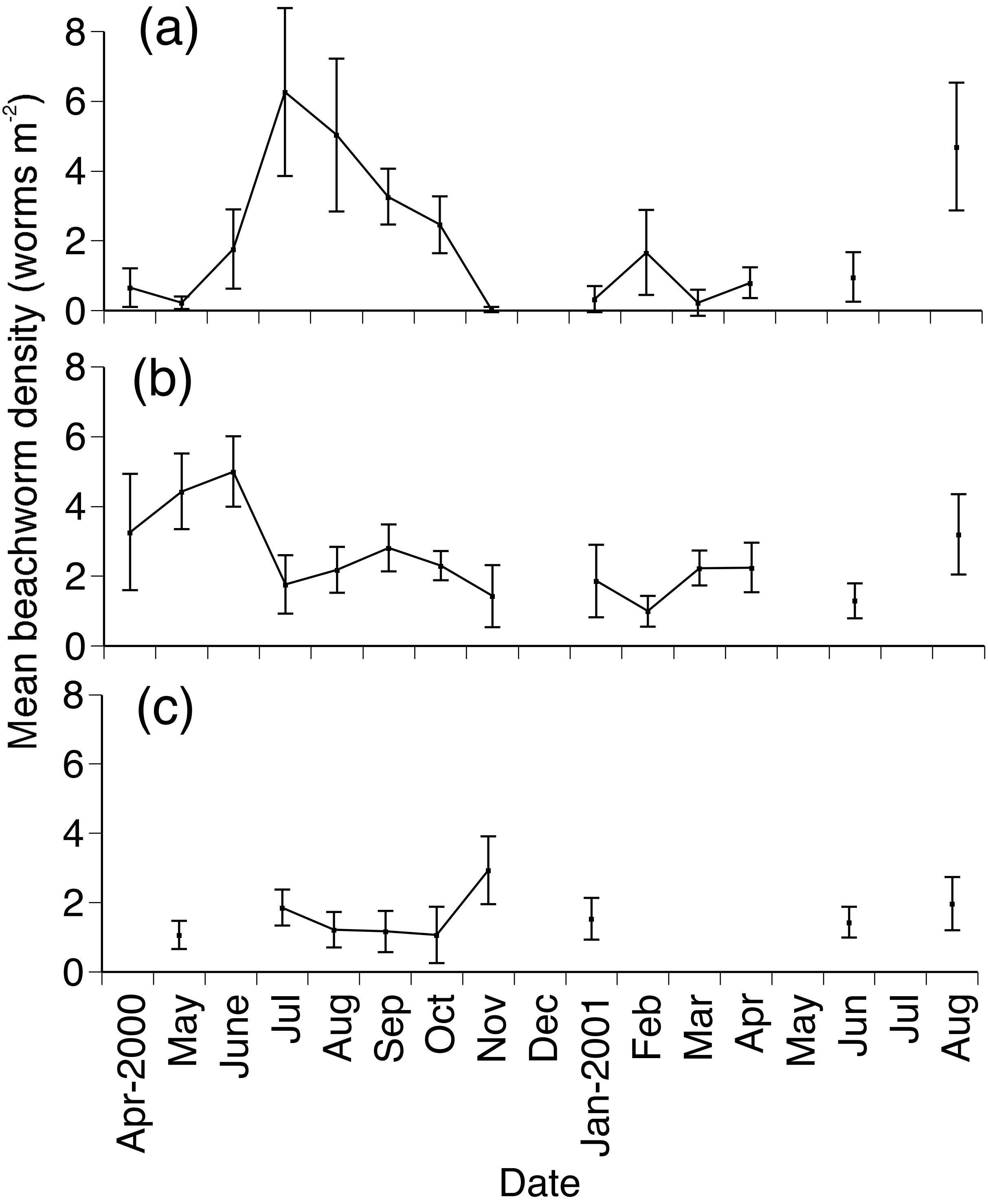

Figure 3.1: Mean (± 95% CL) number of beachworms per m-2 at Site 1 on Teewah-Cooloola beach, SE Queensland, from April 2000 to August 2001, for each of three different heights on the shore (a) high zone, (b) mid zone and (c) low zone. Gaps in the data are for periods when no samping was done and do not represent zeros.

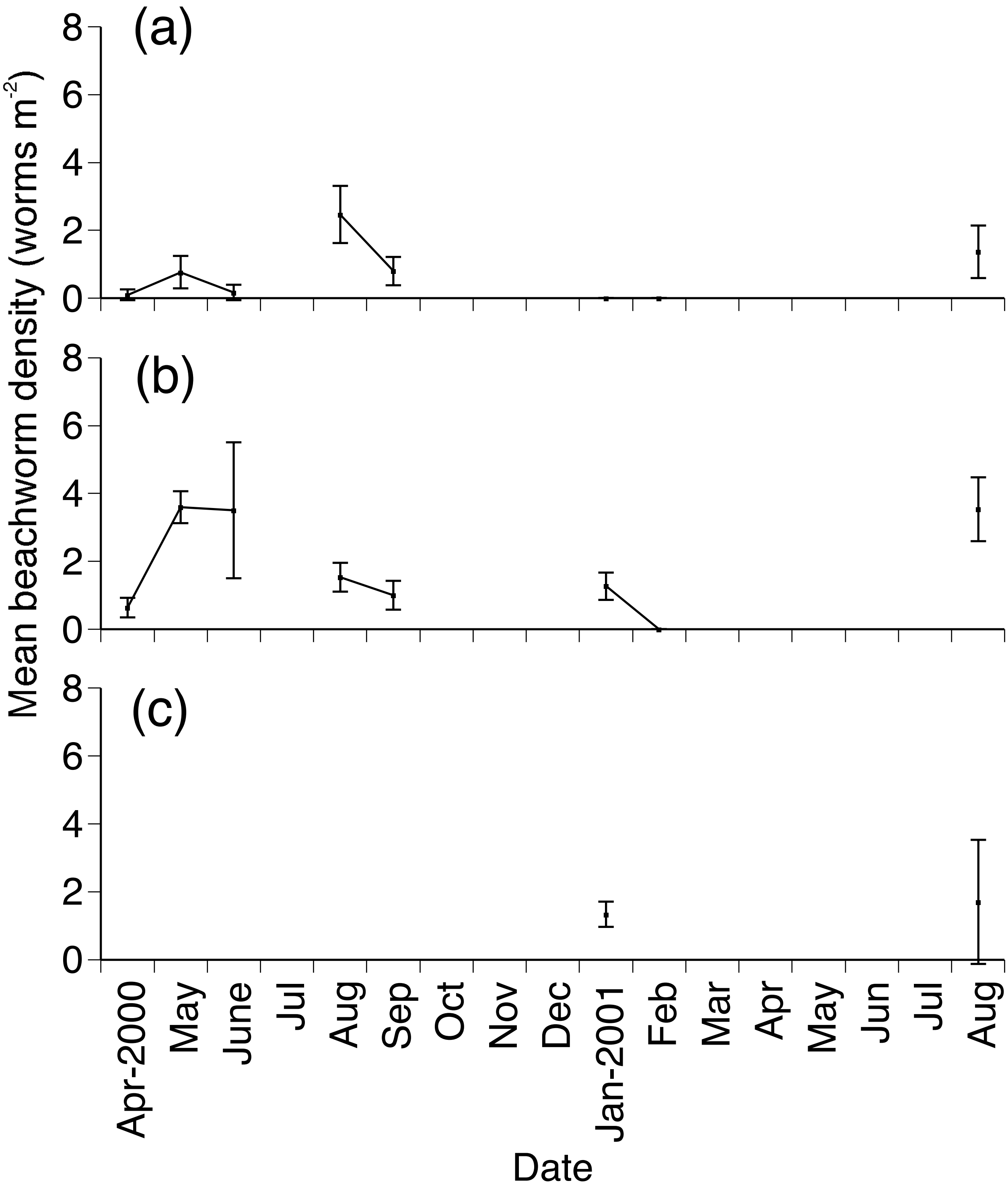

Figure 3.2: Mean (± 95% CL) number of beachworms per m-2 at Site 2 on Teewah-Cooloola beach, SE Queensland, from April 2000 to August 2001, for each of three different heights on the shore (a) high zone, (b) mid zone and (c) low zone. Gaps in the data are for periods when no samping was done and do not represent zeros.

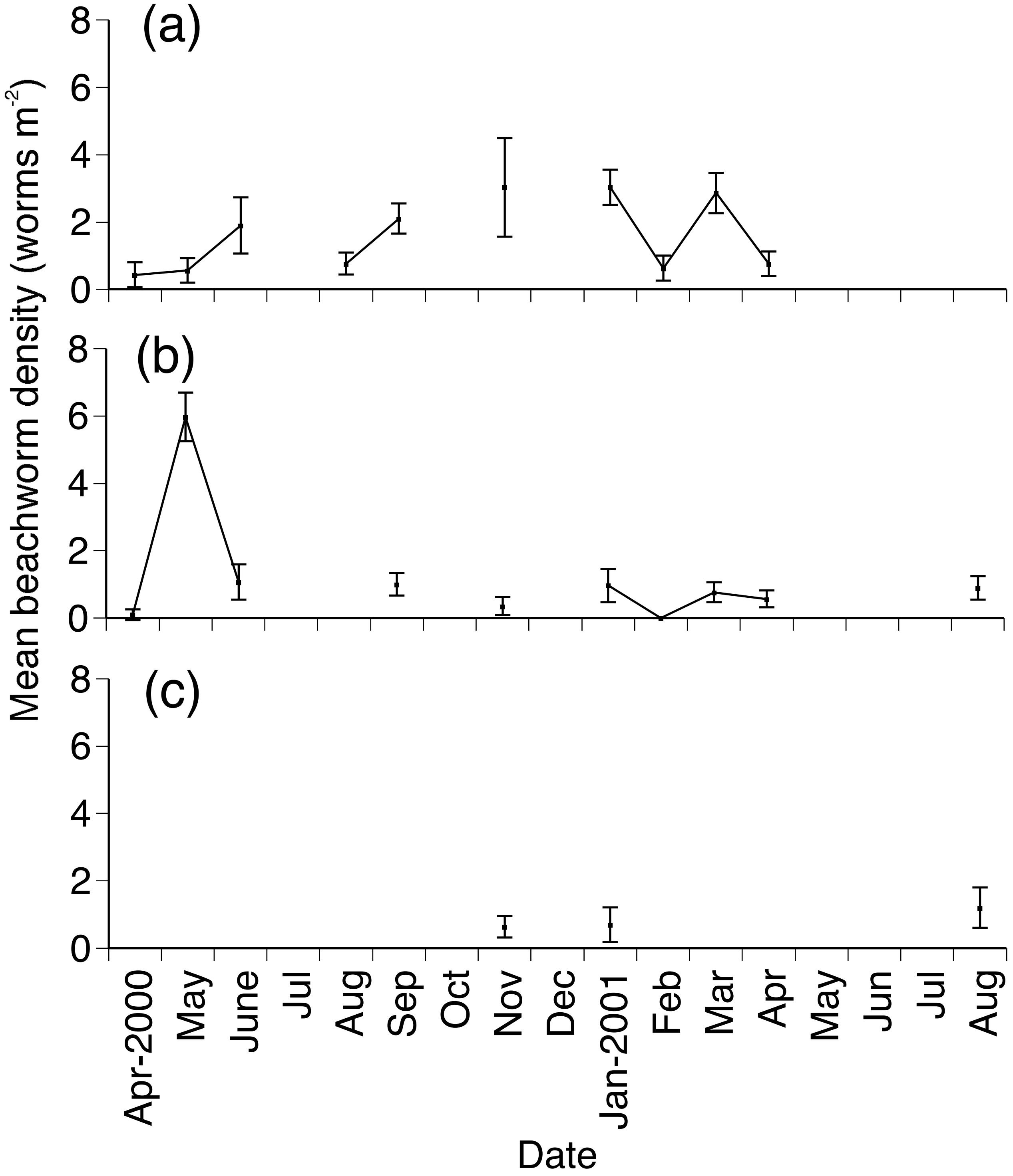

Figure 3.3: Mean (± 95% CL) number of beachworms per m-2 at Site 3 on Teewah-Cooloola beach, SE Queensland, from April 2000 to August 2001, for each of three different heights on the shore (a) high zone, (b) mid zone and (c) low zone. Gaps in the data are for periods when no samping was done and do not represent zeros.

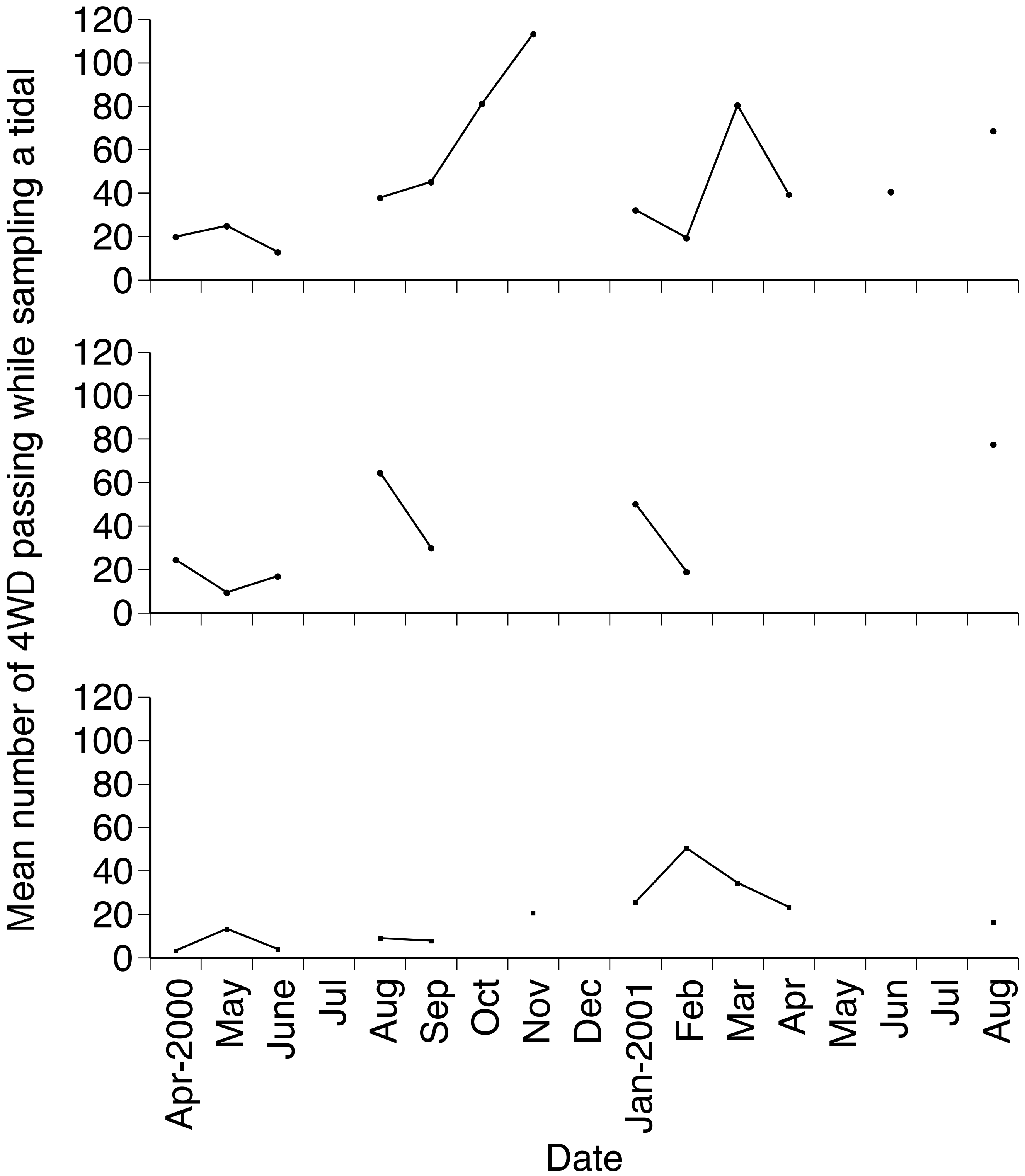

Figure 3.4: Number of 4WD vehciles passing each site Teewah-Cooloola beach, SE Queensland, from April 2000 to August 2001, during the period when sampling was being done. Gaps in the data are for periods when no samping was done and do not represent zeros.

Chapter 4 Conclusions

There were four key objectives in this study

1. To determine where and why beachworms are located on QLD/N.S.W. surf beaches;
2. To determine how the various onuphid species that make up the beachworm fishery are distributed relative to each other and in time;
3. To determine of levels of commercial and recreational fishing effort relate to the yield and sustainability of the fishery;
4. To make recommendations for management of the fishery based on an evaluation of catch and effort data and research of the biology of the worms.

Distribution of beachworms: Data on the patterns of distribution and abundance of beachworms were collected for a single beach in SE Queensland, at three widely space sites and at three different heights on the shore. No data were collected from any beaches in New South Wales or elsewhere in Queensland. Sampling on this one beach in SE Queensland was only done occasionally at two of the three sites. Insufficient data were available on the distribution and abundance of beachworms and the spatial and temporal variation in physical characteristics of the habitats at these sites to draw any conclusions in relation to why different numbers of beachworms were found at different heights on the shore or at different sites along the beach. The available data suggested there was a seasonal trend in the abundance of the beachworms, with more worms present in winter than summer, but this conclusion should be viewed with caution because of the gaps in the data and the lack of a regular sampling programme.

Species-level differences in distribution of beachworms: The data that were collected on the distribution and abundance of the beachworms grouped all the species together, so it was not possible to address this objective in any way.

Sustainability of the fishery: Analysis of log-book data for the commercial fishery indicated that catch rates and CPUE have been relatively stable over the last few years. Analysis of the recreational fishery was based around annual fishing tournaments held on Fraser Island but the data on the abundance of the beachworms was not collected in the same area as the data on recreational fishing effort, so it was not possible to correlate the different patterns. The lack of detailed information on the distribution and abundance of the beachworms at different sites and beaches precluded any general conclusions being drawn about whether commercial or recreational fishing activity related to the availability of the worms. No data on the effects of harvesting, either experimental or based on fishing effort, were collected so it was not possible to assess the sustainability of the fishery.

Management based on the biology of the worms: No data on the biology of the worms were collected. The analysis of the CPUE data for the commercial fishery could not be related to information on the factors controlling the spatial and temporal variation in the abundance of the worms. Methods for sampling to obtain estimates of the abundance of beachworms were developed and tested and would provide for future assessments of stocks. Any future work on beachworms should incorporate a sampling design with sufficient spatial and temporal resolution that would allow an examination of how CPUE in the commercial fishery varied as a function of changes in the abundance of the worms. Development of management guidelines for recreational fishers, such as bag limits, would require information on whether harvesting was impacting on populations of beachworms and a comparison of the magnitude of the recreational catch compared with the commercial catch.

Beachworms are clearly a popular bait species among recreational fishers, with Slimeys (*Australonuphis parateres*) and Stumpies (*A. teres*) being the species of beachworm used. The only bait species used more often than beachworms by recreational fishers were pipis. The recreational fishers surveyed were considered to be more dedicated fishermen than other recreational fishers in general, and nearly all of them harvested their own bait. The number of worms caught by the recreational fishers was small compared with the catch from the commercial fishery commercial fishers catches and it unlikely that recreational beachworm fishing activities will significantly affect beachworm populations. Commercial fishers collect more than 600 000 worms a year in the Queensland beachworm fishery, which would provide enough worms for approximately 60 000 fishing days for recreational fishers (assuming that each fisher used less than 10 worms a day, as determined from the creel survey). Therefore, it is likely that a large proportion of recreational fishers (excluding the more dedicated competition fishers surveyed in this study) purchase their worms from shops.

Commercial fishing effort (CPUE) was greatest during summer and lowest throughout winter. This suggests that the greatest beachworm densities should be found in the summer months and the lowest densities in the winter months or. Although the information from the surveys on the abundance of beachworms was limited, it seems likely that the abundance of worms is greatest in the winter than summer, apparently contradicting the interpretation of the CPUE data for the commercial fishery. This conclusion should be viewed with some caution though given the inherent limitations in the data from the fishery-independent sampling. A more continuous dataset, covering a range of sites is needed in order to obtain reliable estimates of the abundance of the beachworms for comparison with the information for the commercial fishery.

Although fewer fishers participated in the Queensland commercial beachworm fishery than the NSW fishery, the total annual beachworm catches in Queensland were much greater. This is because the CPUE of fishers in the Queensland fishery was three times greater than that of fishers in the NSW fishery. Consequently, beachworm fishing activities are far more profitable in Queensland and beachworm populations are more likely to exploited beyond their maximal sustainable yield. Annual catches in the Queensland fishery have been relatively constant over several years now, and most fishers work for fewer than 100 days per year.

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