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Preliminary assessment and seasonal fluctuations in the fish biota inhabiting the concentrator ponds of Dampier Salt, Port Hedland, with options for the potential application of results

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Fish for the future

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Fisheries research in Western Australia
The Fisheries Research Division of the Department of Fisheries is based at the Western Australian Marine Research Laboratories, P.O. Box 20, North Beach (Perth), Western Australia, 6020. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

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Abstract

The concentrator ponds (CPs) of Dampier Salt, Port Hedland, cover an area in excess of 7 300 ha. Water is pumped from two adjacent, mangrove-lined estuaries at certain times of the year and small and larvae fishes are carried into the ponds, becoming trapped. A survey of the fish biota within the CPs was undertaken at four time periods between May 2000 and February 2001 to identify the species of fishes present and to estimate their abundances and distribution throughout the CPs. Further, the Artemia *resources within the CPs were also assessed for identification of species and quality.*

Forty two species of fishes were recorded from within the CPs, which included species with commercial, recreational and indigenous value, although the catches were dominated by fishes of low economic value. The total fish biomass within the system fluctuated between approximately 60 – 100 tonnes, a similar order of magnitude to the catch of the Pilbara inshore net fishery. The numbers and biomasses within the CPs varied overall and within CPs, most likely as a result of changing water conditions in the CPs, especially salinity, as a result of rainfall, evaporation and seasonal changes. The changes in biomass distribution are a result of fish growth, fish movement and mortality within the CPs at different time of the year and are a major consideration in maintaining the nutrient loading of the CPs to maintain efficient salt production. Artemia *cysts from the CPs were identified as* A.fransciana*, the same species as in many other salt fields in Australia and other parts of the World. A preliminary assessment was performed and indicated that cyst quality was similar to cysts from other parts of Australia.*

A discussion of the outcomes of the project presents a range of future options in regard to the commerical application of the results (Table 9). The application includes preventing the entry of fishes to the commercial aquaculture of certain species, or Artemia*, and includes options for the development of indigenous involvement within the CPs. Initially, the harvesting of fishes within the CPs is possible and relatively simple to implement, especially as some species have a local indigenous value and the infrastructure is readily available. However, the development of a full-scale aquaculture facility should be considered for the long-term. Additional information that may be collected from the CPs for the better management of the CPs is provided for the managers of Dampier Salt.*

1.0 Introduction

Solar salt fields are large producers of salt, the majority of which is exported for use in industrial processes (e.g. plastic manufacturing, C.Sanderson, pers. comm.). In WA there are several large solar salt fields in dry tropical regions, where rainfall is relatively low and evaporation rates are high. Typically, salt water is pumped via a bank of large diameter pumps (greater than 800 mm inlets) from creeks adjacent to the site into the first of an extensive series of concentrator ponds where evaporation occurs, increasing the salinity of the water. This water eventually moves through the series of concentrator ponds, becoming more saline, before being moved to crystalliser and harvesting areas (Burnhard 1991, Thomas 1991).

As a consequence of pumping salt water into these systems, small fishes and invertebrates (i.e. larvae or juveniles) are also pumped into the first concentrator pond. Once in the first concentrator pond, fish and invertebrates that survive the pumping process are unable to leave the system due to one-way flaps between ponds and can only move within the series of concentrator ponds (LeProvost, Semeniuk & Chalmer 1990 b). Due to the large areas of the concentrator ponds involved in the solar salt process (usually several thousand hectares) and large volumes of water pumped into the first concentrator pond, the abundance of fishes within these systems can be considerable (Burnhard 1991).

As a result, a unique ecosystem exists within the concentrator ponds of solar salt fields that is composed of a sub-set of species from adjacent creek waters. Some of the biota within the concentrator ponds are important in the salt production process as some species (e.g. filter-feeding fishes, *Artemia*) increase water clarity and therefore evaporation rates within the ponds, making salt production more efficient (Burnhard 1991). There are also other species of fishes and biota within salt ponds that do not necessarily contribute to water clarity to the same degree as filter feeding fishes. However, as the salinity and other water parameters vary within the ponds due to evaporation, concentration of salts and rainfall, some areas within the concentrator system can become unsuitable for at least some species of fishes, particularly at some times of the year, and mortality events of single or multiple species of fishes are common. Further, species of fishes requiring coastal or oceanic locations and/or salinities to successfully spawn may also suffer mortality as they cannot escape the concentrator ponds. As a consequence, deaths of at least some species of fishes are observed within the concentrator pond system at particular times of the year (Dampier Salt, pers. comm.). When a fish-kill is observed, the salt producers require the carcasses to be removed and disposed of, increasing the costs of production and impacting on the efficiency of salt production as water pumping into the system is often stopped (Dampier Salt, pers. comm.).

Besides compromising salt production, large mortalities of fish are also wasteful, particularly as some of the species are likely to have commercial and/or recreational value (LeProvost, Semeniuk & Chalmer 1990 a, LeProvost, Dames & Moore 1996). The potential of harvesting particular species of fishes at particular times of year has the benefits of utilising this source of protein either directly as fish sales or to support aquaculture industries, thereby increasing the returns to the salt producers by fish sales. Further, targeted fish harvesting may reduce the occurrence of fish deaths, producing associated cost-savings and maintaining the efficiency of salt production. However, prior to considering any option, a range of biological information about the biota within the concentrator ponds needs to be collected.

Of equal or greater interest in solar salt fields is the presence of the brine shrimp, *Artemia*, which are encouraged in solar salt systems as their feeding activities increase the clarity of the water and enhance evaporation rates, and therefore the efficiency of salt production (Burnhard 1991, Rahaman *et al.,* 1993, Tyler 1996). However, as water within the concentrator ponds increases in salinity, resistant cysts are observed in higher salinity concentrator ponds and large cyst beds are often seen on the banks of the salt fields (Dampier Salt, pers. comm.). These resting cysts may hatch as a result of changes in salinity due to freshwater input by rain. However, *Artemia* are in high demand by many aquaculture industries as a source of food for early stage fishes (Hoff and Snell 1987, Triantaphyllidis *et al.,* 1993) and return a high premium. Thus, the potential of cyst harvesting or the construction of purpose built *Artemia* facilities is also of great interest to operators of solar salt fields. As a first step, the biological characteristics of the *Artemia* present in the solar salt fields must be assessed.

The Dampier Salt (DS) concentrator ponds, near Port Hedland Western Australia (20.31ºS, 118.58 ºE), are typical of solar salt producers in many parts of the world. The concentrator ponds in this study cover an area of approximately 7 273 ha divided into 9 large ponds ranging in size from approximately 381 ha to 1225 ha (Table 1). Water is pumped from two tidal creeks (Rock Cod Hole Creek and Ridley Creek) on high tides into pond 0A (Figure 1) at particular times based on weather patterns and evaporation rates. Although Dampier Salt is a major producer of industrial grade salt, the large number of fishes observed in the concentrator ponds and the occurrence of fish-kills has prompted a review of the potential of the biotic resources within the concentrator ponds by the regional development agency, the Pilbara Development Commission (PDC). The overall objectives of the project can be divided into three categories;

1. Assessment of the biota to provide information to the salt producer on the management of the salt fields to maintain conditions for optimal salt production;

2. Assessment of the biota in regard to the potential for harvesting of resources from the existing concentrator ponds; and

3. Assessment of the biota and facilities in regard to the potential for the development of an aquaculture facility.

Specifically, these objectives will be addressed by;

- collecting information on species composition, recruitment and abundances in the concentrator ponds;

- estimating fish biomass and the distribution of fish stocks within the concentrator ponds;

- estimating fish biomass within the ponds for use in nutrient balance calculations by the salt producer;

- identifying the strain(s) of *Artemia* present in the concentrator ponds and evaluating the quality of *Artemia* cysts;

The above objectives will provide information for a preliminary evaluation of the potential for fish harvesting from the concentrator ponds and the opportunities and potential for fin-fish and *Artemia* culture at Dampier Salt. Although the information collected above will be of direct relevance and importance to DS and the PDC, information on species composition within the concentrator ponds would also provide an indication of species composition in adjacent tidal, mangrove-lined creeks in the Pilbara. Further, preliminary information on the recruitment patterns of some species of fishes in this region may also be collected, providing information relevant to the management of coastal fish resources of the Pilbara.

2.0 Methods

2.1 Sampling sites

All sampling occurred at the Dampier Salt concentrator ponds located approximately 30 km east of Port Hedland, Western Australia. There are a total of 9 concentrator ponds in the complex covering an area of approximately 7 273 ha (Figure 1). Water is pumped directly from two creeks (Ridley and Rock Cod Hole) directly into concentrator pond (CP) OA on high tides around the spring phase of the lunar cycle (tidal regime fluctuations of approximately 7 metres occur in this region) when evaporation rates are high. The salt fields are in the dry tropics of Western Australia where the average rainfall is approximately 311 mm per annum (Figure 2).

The CPs have an averaged depth of 0.7 m but some areas within the CPs may be up to 3 metres deep. The sediments range from fine muds to coarse sands. The bund walls are constructed from granitic rocks and some areas of mangroves exist within the system. CPs are linked to adjacent CPs by a single point, usually a gate several metres wide with a one-way flap in some instances. However, a long channel links CP OB and CP 1. Water moves uni-directionally through the system from CP OA to CP 8 by two pumping stations (intakes) on CP OA and a pumping station linking CP 6 to CP 7.

Four sampling periods were selected to reflect the changing climatic conditions typical of the dry tropics in Western Australia. The four periods were May/June 2000 (early dry season, "Autumn"), August 2000 (dry season, "Winter"), November 2000 (pre-wet season, "Spring") and February 2001 (post-wet season, "Summer"). During a preliminary visit to the site in February 2000, fish were observed in CPs OA, OB, 1 and 2. Sampling through this project focussed on these four CPs, plus CP 3.

2.2 Fish sampling methods

2.2.1 Sampling locations and effort

Sampling effort for fishes was spread between ponds OA, OB, 1, 2 and 3. Sampling effort for *Artemia* was focussed on ponds 5 and 6, with other ponds visually assessed. Other sites were also examined including the major connection between pond OB and pond 1, and Rock Cod Hole and Ridley Creeks. However, it was not possible to sample the creek sites except during trip 4 due to access problems and tides.

Ponds OA, OB and 1 were given the most effort due to the high numbers of fishes observed and the anecdotal information provided by Dampier Salt staff. Each pond was given three units of effort at each of two locations. Each unit of effort consisted of three seine shots and three gill-net sets, each gill net set consisting of three gill-nets. An additional unit of effort was provided into pond OB due to the large size and structure of this pond (Figure 1).

2.2.1.1 Seine net

A seine-net was used to target small species of fishes within the salt-field system. The seine net used was 40 metres long by 2 metres deep, constructed of 25 mm mesh, with a cod-end of 9 mm mesh. The seine was set on a bank from a small boat. The net was slowly set from the boat, while the boat was reversing in an arc, back to the shore line. The area sampled by each seine shot was approximately 255 m^2. For each unit of effort, three seine-shots were performed, with each seine-shot being at least 50 m distance from any other shot, thus assuring independence of sampling.

2.2.1.2 Gill nets

Three gill nets of three different mesh sizes were used. Each gill net was 30 metres long and 2 metres deep, with 50 mm, 100 mm or 150 mm mesh size. Each unit of effort employed all three nets for a 1 hour soak duration. On re-setting, the position of the gills nets assured that all nets sampled independently of each other. The exception to the soak-time occurred in the ponds of higher salinity (ponds 2 and 3). In these ponds, gill nets were set in the late afternoon and retrieved early the following morning, giving a soak time between 15 and 18 hours. For these overnight soaks, catch and effort was standardised to one-hour to allow comparison among CPs and times.

2.2.1.3 Supplementary sampling

Areas where seine nets or gill nets could not be used (e.g. rock-lined channels) were sampled via hook-and-line. Visual observations were also made to identify extra species. The salinities of all CPs at all times was provided by staff at Dampier Salt.

2.2.1.4 Sampling of adjacent creeks

Water for the CPs is pumped from two mangrove-lined creeks adjacent to CP OA. These creeks, Rock Cod Hole Creek and Ridley Creek (Figure 1), are relatively small with a channel width of less than 30 m at the pumping stations. The creeks are exposed to a tidal range of approximately 7 metres during spring tides. Due to the height of the bund walls of the CPs (approximately 4 metres) and the material of the bund walls (large granitic rocks) access to the creeks adjacent to the pumping stations is limited. As a result, sampling of the creeks only occurred during Summer 2001 with the use of a single gill net set (100 mm net only set for approximately 1 hour) and hook & line sampling (approximately 1 hour at each pumping station). A seine net was not able to be used due to the lack of suitable banks on which to set and retrieve the net. All fish captured were identified to species, measured and released.

2.2.2 In-field processing of samples

After each net retrieval, each sample of fish was processed. For seine-net samples this included the retention of all fish from a sample and weighing the entire sample. For gill-net samples, fish were identified to species and a length (Total Length (TL) mm) and weight (grammes) recorded. A sub-sample of fish were retained and frozen, with the remainder of the fish disposed of as per Dampier Salt requirements. For some larger fishes, the head and guts were frozen to reduce transport bulk. Frozen samples were stored at Dampier Salt or a transport company for return to WAMRL. At least one representative of each species collected was returned to WAMRL for positive identification.

2.2.3 Processing at WAMRL

On return to the laboratory, fish were identified to species and length and weights taken for each individual. Species were identified using the identification guides of Allen (1985), Allen and Swainston (1988) and Heemstra and Randall (1992). A sub-sample of common species was analysed for gut-contents, reproductive status and possible age-determination studies in the future. Fish were then disposed as per WAMRL guidelines.

2.2.4 Data analysis

Data collected was stored in a Microsoft Access database. Data was converted to catch-per-unit-effort (CPUE) for each net type. Briefly, the total weight or numbers of fish is divided by the soak-time of the gill nets or the number of the seine net shots (3) for each site within each pond. This way, means and error-estimates can be calculated for each gear type within each pond, and comparisons among ponds and among times can occur.

Estimates of biomass and total numbers of fish within each pond were derived for each gear type. For the seine net, the area of the each seine-shot (255 m^2) and the length of bank sampled (25.45 m) are known (see appendix 1). The length of bank in each pond that is able to be seined was estimated from aerial photos of the ponds supplied by Dampier Salt. Biomass estimates and estimates of total numbers are calculated by multiplying the average biomass and numbers of fish, respectively, captured by the seine within a pond, multiplied by the perimeter bank length, divided by the length of bank that each seine samples. That is;

Biomass Estimate = (<u>Mean Weight of Catch per Seine) x (Perimeter of Bank</u>)
(from Seine) (Bank Length sampled by each shot).

A similar equation was used for total fish numbers. The error term of each estimate is calculated in a similar way using the standard errors generated by the estimates of mean value per seine.

Estimates of biomass and total numbers from gill nets are more difficult to establish as gill nets do not sample a discrete area or volume of water due to the static nature of this type of gear. Typically, gill net estimates are expressed as catch-rates (CPUE) or proofed by echo-sounders to estimate fish densities and biomass. Although CPUE can readily be calculated, it provides only a relative estimate of abundance. Echo-sounding within the Dampier Salt fields is inappropriate due to the shallow nature of the water bodies (average of 0.7 m). As a result, two alternative measures were used to estimate the numbers and biomass of fishes in the concentrator ponds, based on gill net area. These estimates were derived by using the area of net used in each set.

The first estimates of fish numbers and biomass ("Low" estimates) were calculated by using the total area sampled by each gill set. Briefly, each net is 30 m long and is separated by other nets in the set by 60 m (2 x the length of each net). Thus each set of gill nets has a linear distance of approximately 210 m. As fish can approach from either side of the gill net, and as gill nets are set in relation to water movement, the area sampled can be assumed to be broadly circular and is calculated using the formula of a circle. That is;

Area Sampled by Each Gill Net Set $= \pi \times (\text{radius}^2)$
$= 3.1416 \times 210^2$
$= 138\ 544.2\ m^2$

The second estimates of fish numbers and biomass ("High" estimates) were calculated by using the total area sampled by each individual gill net within a set. In these estimates, a similar calculation was made, but of the individual three nets within a set. As each net is 30 m long, the area sampled per set was the sum of the area of three circles of 30 m radius each. That is;

Area Sampled by Each Gill Net Set $= 3 \times (\pi \times (\text{radius}^2))$
$= 3 \times (3.1416 \times 30^2)$
$= 3 \times 2\ 827.44\ m^2$
$= 8\ 482.32\ m^2$

To estimate the total numbers and biomass (from gill nets) of each pond for each estimate, the mean biomass from gill nets was multiplied by the total area of each pond (from Dampier Salt records) and divided by the area sampled by each gill net set for both the Low and High estimates. That is;

Biomass Estimate = (Mean Weight of Catch per Set) x (Total Pond Area)
(from Gill Nets) (Area sampled by each set).

A similar equation was used for total fish numbers. The error term of each estimate is calculated in a similar way using the standard errors generated by the estimates of mean value per gill net set. Full explanations of the calculation of fish numbers and biomass from both types of gear are provided in appendix 1.

Although gill nets do not provide ideal estimates of biomass and fish numbers, as similar techniques were applied to all data collected, these estimates are robust enough for comparative purposes among times and CPs. Alternative estimates do exist but are more labour-expensive and logistically difficult (Appendix 2) and may not necessarily provide better or more robust estimates than the techniques used above.

Total estimates of biomasses and fish numbers were calculated as the sum of the estimates generated for each gear within each CP, as the gears (seine and gill nets) will have little overlap in the areas in which they can be used.

2.2.5 Nutrient estimates

The total nutrient load for each pond can be estimated from total biomass estimates. Briefly, all fish are comprised mainly of water (approximately 70 - 75 % by weight) and the rest composed of protein, lipid, and ash (elements), plus a small amount of carbohydrate (Molony 1993, Molony and Sheaves 1998 a, b). Proteins, lipids and carbohydrates are carbon and nitrogen-based compounds. Thus a broad estimate of total nutrient load can be generated by multiplying the total biomass estimates by 0.25.

2.3 *Artemia* sampling methods

2.3.1 Collection of samples

Sites for *Artemia* collection were selected by the presence of cyst banks and by anecdotal knowledge provided by Dampier Salt staff. Cysts are usually observed floating on the surface of more denser (more saline) waters and the banks of CPs 5 and 6 were selected. Cysts were collected soaked in brine and stored chilled. On return to WAMRL, cysts were cleaned via washing with saline and freshwater and dried. A sample was sent for identification and quality assessment to the Laboratory of Aquaculture and *Artemia* Reference Centre,
Ghent University, Belgium.

3.0 Results

3.1 Weather conditions during the sampling period

The study period occurred during a wetter than average year (Figure 2). This is mainly as a result of the rainfall generated by cyclone Steve that deposited large amounts of rain as it passed Port Hedland in March 2000. Although cyclone Steve was unusual in that it traveled from North Queensland, across the Northern Territory and into Western Australia, the Pilbara region is typically affected by cyclones at a rate of approximately 1 per year. However, in many years the rainfall in the Pilbara region, and specifically in the area around the Dampier Salt Concentrator Ponds, is minimal, even if cyclones do occur (e.g. minimal rain was generated by cyclone Vance, 17 – 24 March 1999, that bypassed Port Hedland). Thus, heavy cyclonic rains are generally expected once every three to four years.

The pattern of rainfall during the sampling period and the extent of the rain resulted in limiting access to the CPs, suppressing the salinity of the water within the CPs and causing *Artemia* cysts to hatch. Although rainfall was relatively high during the sampling period, the daily evaporation rates were similar to the long term averages and thus the pattern of salinity change in the CPs was expected to follow a similar trend to other years. It should also be noted that Dampier Salt manage high-rainfall periods by closing the connections among ponds and ceasing the pumping of creek water into CP OA, until evaporation causes the salinity in creek waters and CPs to return to appropriate levels.

3.2 Salinity

The salinity of the water in the CPs increased from CP 0A to CP 3 (Figure 3). In CP 0A the water pumped into the system is the same salinity as water within the two creeks (approximately 40 ‰). Salinity reached approximately 115 ‰ in CP 3 in the tropical winter (August 2000). Although the salinity within the system is dictated by the salinity of the water within the creek and slowly increases due to evaporation in the concentrator ponds, the effects of rainfall (Figure 2) result in a rapid decline in salinity. This decline is most obvious in CPs 2 and 3 between the peak in winter (August 2000) and subsequent seasons.

3.3 Fishes

A total of 42 species of fishes were identified from seine and gill nets samples in the CPs (Table 2). Most species of fishes were of little or no economic value although they may be an important fodder species (e.g. *Allanetta mugiloides*) for other predatory species of fishes in the CPs and birds that inhabit the CP area (e.g. sea eagles). Most species of fishes were in their highest numbers and biomasses in ponds 0A or 0B although some species were more abundant in CP 1. The number of species recorded in from the CPs declined as the salinity increased, with the lowest number of species recorded from CPs 2 and 3.

A sub-sample of the fishes collected were examined for gut contents and reproductive status and most of the common species were predatory on smaller fish and invertebrates (Table 3). However, *Valamugil buchanani* and *Chanos chanos* consumed algae and small food items (e.g. fish eggs). Many of the fishes examined had mature or maturing gonads although no evidence of spawning was recorded apart for small species (e.g. *Apogon* spp). Six species of fishes were identified that had a value to indigenous communities as food fishes.

The abundance of fishes varied throughout the sampling period and among CPs. In terms of numbers, seine net samples were dominated by small planktivorous fishes in all CPs although predatory species dominated the biomass rankings (Table 4 a). From gill net samples (Table 4 b), ranks of both abundance and biomass were often dominated by larger fishes that fed at either low trophic levels (e.g. C*hanos chanos*), or on small fishes (e.g. *Elops hawaisiensis*), particularly in CPs 1, 2 and 3

The diversity of the species collected by seine nets were similar within CPs OA, OB and 1, although generally more species were recorded from CPs OA and OB (Figure 4). Throughout most of the year, similar numbers of fishes were sampled via seine nets from CPs OA, OB and 1, with slightly more fishes recorded from CP OA (Figure 5). The only exception was during Autumn 2000 when the highest numbers of fishes were recorded from CP 1. The average biomass of fish from each seine shot varied throughout the year (Figure 6) with the highest biomasses recorded from CP OA in Autumn 2000. Comparatively, the pattern of biomass from CP OA was the inverse of CP 1. However, CP OA generally had the highest biomass with biomass declining in CPs OB and 1.

Gill net samples produced far fewer fishes than seine net samples (Figure 7). Although most gill-net samples produced less than 20 fish per shot, the highest catches were from CP 3, and to a lesser extent CP 2, which were typically dominated by *Elops hawaiiensis* and *Amniataba caudovittatus*. However, it must be noted that longer soaks were used to sample CPs 2 and 3 and the larger number of fishes may simply reflect the soak time. Further, few fish were captured via gill nets during Spring 2000 from CP 2, with no fish captured from CP 3.

The diversity of fishes recorded from gill net samples showed a similar pattern in CPs OA, OB, 1 and to a lesser extent in CP 2. That is, relatively few species were recorded from the CPs for most of the year, with a much higher number of species recorded during Summer 2001 (Figure 8). In contrast, the number of species recorded from CP 3 was highest in Autumn 2000.

Due to differences in soak times (see methods), reporting of fish biomass sampled via gill-nets can be presented as total biomass estimates (Figure 9) or as biomass per hour (Figure 10). From both figures, biomasses fluctuated greatly throughout the sampling period and tended to be the highest in Summer in all CPs. The highest levels of biomasses was recorded from CPs 1, 2 and 3 with CP 1 recording the highest biomass per hour at all times of the year.

Gill nets are one of the most size-selective fishing gears (Hubert 1996). As such, although the average size of fishes recorded was similar among all CPs (Figure 11), much smaller fish were collected from CPs 2 and 3, particularly after Autumn. It should also be noted that the average length of fishes sampled by gill nets in CP OA declined in Summer 2001.

3.4 Estimates of the numbers and biomass of fishes in the CPs

The data collected allowed two estimates of the total number of fish and the biomass of fishes within CPs up to CP 3 to be calculated for each of the four sampling periods. The two estimates, "High" and "Low", reflect different methods in the calculation of the estimates based on different calculations of the sampling area of the gill nets (see methods section and appendix 1). Estimates of fish numbers and biomasses from the CPs throughout the sampling period were used to estimate the total number of fishes and total biomass of fishes within each CP and for entire system (up to CP 3) (Tables 5 and 6).

Similar numbers of fishes were present throughout all sampled CPs at on all sampling occasions, with slightly higher numbers present in Autumn and Summer (estimated at approximately 800 000 fishes) (Table 5). However, the distribution of fishes within the five CPs varied throughout the year. For example, with the exception of the Autumn 2000 samples, the highest number of fishes was always in CP OB, with CP OA having the second highest number of fishes in Winter and Spring while CP 1 had the second highest number of fishes in Summer 2001 and the highest number of fishes in Autumn 2000. Relatively large numbers of fishes were recorded in CP 3 in Autumn and Summer although extremely low numbers were estimated in Winter, with no fishes recorded from CP 3 in Spring. It should also be noted that the largest numbers of fishes were recorded from seine net samples and that the difference between the "high" and "low" estimates are relatively modest due to most fishes being captured by seines.

Similarly, the biomasses of fishes captured within the CPs also varied throughout the year. As most of the fishes captured in seine nets were small and of low weight, the "high" and "low" estimates vary considerable due to the estimates of biomasses from gill-nets (Table 6). It should also be noted that seine samples were not taken from CPs 2 and 3. For all sampling occasions, the highest biomasses were always in CP 1, expect for Autumn, where a high biomass was estimated for CP 3. The biomass in CP OA was similar throughout the year and always lower than the biomass in CP OB. The biomass from the two highest salinity CPs (CP 2 and 3) fluctuated dramatically, between very high levels in Autumn to very low levels in Spring.

As the estimate of the nutrients associated with fishes within the CPs was calculated using a standard proportion (0.25) of the biomass estimates, the patterns of nutrient levels due to fish within the CPs followed a similar pattern to the biomasses estimates (Table 7). It should be noted however, that the levels of nutrients due to fishes within the CPs was similar for most of the year within CPs OA, OB, and 1, with the exception of relatively low levels in OB in Winter and in CP 1 in Autumn. However, the nutrient levels in CPs 2 and 3 fluctuated greatly throughout the year from very high levels to zero.

In previous reports, more detailed data was provided for each trip. This is presented in appendix 3 for comparison and consistency.

3.5 Fish fauna of adjacent tropical estuaries

Only three species of fishes were reported from both creeks (Table 8). Although these species were also present within the CPs, many other species present in the CPs were not recorded. As the seine net was not able to be used within the creeks, the lack of smaller fish and small species of fishes does not necessarily indicate that they were not present in the creeks.

3.6 *Artemia* within the CPs

Although anecdotal records of large numbers of *Artemia* cysts from the CPs exist (Dampier Salt pers. comm.) cysts were only obtained during Spring 2000 (Trip 3), probably as a result of the cyclonic rainfall earlier in 2000 (Figure 2). These cysts were collected from the banks and water surface of CP 5 and sent to the Laboratory of Aquaculture and *Artemia* Reference Centre, Belgium, for identification and quality assessment. The species was identified as *Artemia franciscana* and had an average size of 240.48 µm. There were approximately 251 269 (± 12 018) cysts.g^{-1} in the sample collected from the Dampier Salt fields. The hatching of cysts from the sample was synchronised and had a rate of 87.13 % after 24 hours at 28 °C, a standard measure.

The abundance of fatty acid methyl esters (FAME) were quantified from the sample of *Artemia* cysts collected from the Dampier Salt fields. The sum of the levels of highly unsaturated fatty acids (HUFA) in the sample was 9.3 %. The levels of two critical fatty acids (FA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), were relatively low at 8.6 % and 0.1%, respectively. Overall, the *Artemia* cysts collected from the Dampier CPs were of a similar quality to cysts from other Australian sites. Full details are provided in appendix 4.

4.0 Discussion

4.1 Physical characteristics of the CPs

Although water from two mangrove-lined creeks is pumped into CP OA, evaporation and rainfall are the major influences on the salinity regime within the CPs. Water pumped from the two tidal creeks will be iso-osmotic with creek water and may be of similar salinity to adjacent seawater; however, water cannot re-enter the creeks once in CP OA due to one-way gates. Although the salinity of the waters within the CPs increased from CP OA to CP 3, the salinity of the waters did vary throughout the sampling period due to rainfall and evaporation (Figure 2). The impact on the biota within the CPs is that salinity will slowly increase due to evaporation but may decrease rapidly due to significant rainfall, especially during cyclone-affected years (approximately 1 in 4 years).

The range of salinities within the CPs departs dramatically from salinities in most tropical estuaries. In estuaries in the dry tropics of Queensland, high salinity water (in excess of 70 ‰) can exist at some times of the year (Sheaves 1996, Molony and Sheaves 2001), due to tidal inundation of salt flats and the re-dissolution of salt crystals. In contrast, although salinities within the CPs were affected by evaporation and rainfall and did fluctuate throughout the sampling period (Figure 2), the salinity of CPs OB, 1, 2 and 3 did not fall to salinities similar to the water in the adjacent creeks. Nonetheless, dramatic changes in salinity were recorded. For example, although CP 3 had the highest salinity of any pond surveyed throughout the project (69 - 113.7 ‰), salinity was reduced by 31 ‰ within 11 weeks (November 2000 to February 2001) (Figure 3). The extremely high salinities are likely to restrict the diversity and abundance of organisms within the CPs.

4.2 Fish resources in the CPs

In comparison with previous studies on tropical estuarine ichthyofauna, the number of species recorded within the CPs was relatively low, with only 42 species recorded. Although a low number of species were recorded within the CPs, a similar number of species (n = 41) were recorded from CPs 1 and 2 in a previous study (LeProvost, Semenuik & Chalmer 1990 b). Further, the number of species recorded is higher than recorded for other salt fields in northern Western Australia, (20 species recorded from Dampier Salt, (LeProvost, Semeniuk & Chalmer 1990 c)).

Previous studies in Australian tropical estuaries have identified up to 197 species of fishes (Robertson and Blaber 1992), although as few as 38 species have been recorded (Leanyer Creek, Northern Territory (Davis 1988)). Although the two creeks adjacent to the CPs produced only 3 species, this is likely to reflect the limited effort placed on these sites as a result of limited access. Information currently being collected by a Department of Fisheries led research project (S. Newman pers. comm.), will provide further information of the diversity of coastal fishes in waters adjacent to the CPs.

The low number of species recorded from the CPs, relative to other tropical estuaries, may be caused by a variety of reasons. For example, the low numbers may be due to the timing of pumping water from the creeks. Most water is pumped from adjacent creeks into CP OA on high tides during times of the year when rainfall is typically low (tropical winter), avoiding periods of high, cyclonic rains (tropical summer). Thus, only species present in the creek during times of pumping are likely to be moved into the creek. As the recruitment of fishes to tropical estuaries principally occurs in the wet season (November to February, Figure 2) (Robertson and Blaber 1992), it is not surprising that the number of species recorded within the CPs is relatively low as water pumping is typically reduced during these periods (Dampier Salt, pers. comm.). Further, fish within the CPs must be able to survive the pumping process. Finally, the diversity of habitat within the CPs is limited, dominated by open, sandy areas with little structure. In contrast, tropical estuaries are structurally diverse (Robertson and Blaber 1992; Sheaves 1996) and thus some species that survive the pumping process may be habitat limited. However, some species were found associated with available structure within the complex. For example, large numbers of the estuarine cod, *Epinephelus coioides,* were observed in the rock-lined channel linking CPs 0B and 1, while the bream, *Acanthopagrus latus,* were found close to rock walls in CPs 0A and 0B.

Several species of macro-invertebrates were also observed within the ponds and channels of the CP complex. The mud crab (*Scylla serratta*) was common in many sites which contained structure (e.g. mangrove areas of CP 1 and the channel) while the blue swimmer (*Portunus pelagicus*) was collected from gill net samples in CPs OA and OB. At least one species of penaeid prawn was observed as were carapaces of dead grapsid crabs (CP 0A), commonly found in mangrove areas (Sheaves and Molony 2000). One species of fiddler crab (*Uca* spp.) was observed in high abundances in Rock Cod Hole Creek during low tides, although no individuals were observed within the CPs. Although macro-invertebrates were observed the results are not likely to be indicative of true diversity or abundance.

Most of the species of fishes recorded from the CPs were piscivores or filter feeders and the highest abundances were confined to the first three CPs (OA, OB and 1) (Table 3). While filter feeding fishes, like *Chanos chanos*, promote salt production by maintaining water clarity and thus high evaporation rates (Burnhard 1991), piscivorous fishes typically return the highest commercial prices and are attractive to recreational fishers.

More species of fishes and higher abundances were recorded from seine samples than from gill net samples. Due to the use of seine nets (i.e. active sampling) and the small mesh size, catches were dominated by fishes of small species (e.g. baitfishes such as *Illisha striatula*) although larger fishes were also recorded albeit less frequently (e.g. *Epinephelus coioides*) (Table 4 a). As many of these smaller species have a short life history (e.g. *Ambassis* typically between 1 – 2 years (Molony and Choat 1990)) and recruit throughout the year in tropical estuaries (Molony and Sheaves 1998 b), the reproduction of these fishes within the CPs may be possible, at least in CPs with relatively low salinity (e.g. CPs OA and OB). However, larger species recorded from seines (e.g. *Epinephelus coioides*, *Lates calcarifer*) typically have an offshore migration prior to spawning (Sheaves 1995) and thus reproduction within the CPs is unlikely. As a result, although some smaller species may be self-recruiting within the CPs, many of the larger, and commercially or recreationally important species must recruit to the CPs from the adjacent creeks via the pumping process. Other species recorded within the pond that have a recreational and/or commercial value, such as *Acanthopagrus latus*, may be able to spawn within the CPs, albeit at a relatively low success rates due to the extreme salinity regime within the CPs (e.g. Molony and Sheaves 2001).

Gill nets, due to their passive nature and large meshes, captured mobile and relatively large species of fishes (Table 4 b). Predatory pelagic species, such as *Elops hawaiiensis*, tended to dominate the catches, although some recreationally important species, such as the queenfish (*Scomberoides commersonnianus*), was the most abundant species in CP OB. As expected, the number of species declined in CPs of higher salinity although large numbers and weights of *E.hawaiiensis* were recorded in all CPs, including CP 3. Surprisingly, the length-frequency distribution suggests that *E.hawaiiensis* may be reproducing within CPs of higher salinity (i.e. CPs 1, 2) at least during some parts of the year due to the presence of small fishes in higher salinity CPs and not in CPs of lower salinity (e.g. CP OA) (Figure 12). This is supported by the presence of mature *E.hawaiiensis* from the CPs (Table 3). In comparison, a pelagic fish such as *S.commersonnianus* showed a much more restricted distribution and small fishes were rarely recorded (Figure 13), thus reproduction of this species within the CPs is unlikely.

Gill net samples also revealed that the most abundant, large species of fish in the CPs was *E.hawaiiensis*, not the milkfish, *Chanos chanos*, as was expected from previous literature on fish species within solar salt fields (e.g. Burnhard 1991). Although *C.chanos* was captured in most CPs, it was never recorded in CP 2, despite similar techniques used throughout the study and the recording of *E.hawaiiensis*, which has a similar pattern of behaviour. Further, as fish cannot move into ponds of lower salinity due to one-way flaps between ponds (LeProvost, Semeniuk & Chalmer 1990 c), *C.chanos* must be self recruiting at least in some of the CPs in which it was recorded, otherwise individuals of *C.chanos* would be expected to be captured from CP 2 at least during some periods of the year.

Similarly, large numbers and ranges of sizes of the yellowtail trumpeter, *Amniataba caudovittatus*, were recorded from all CPs. Although the largest numbers of this species were recorded from CPs OA and OB, individuals were captured in all CPs at all times, except for CP 3 in August and November. A range of reproductive states were recorded from individual *A.caudovittatus*, including mature specimens (Table 3) and the length-frequency information suggests recruitment into or within CP OA in August and potential movement to CP OB in November (Figure 14). However, self-recruitment within the CPs is evidenced from the recording of small fishes in CPs OA, OB and 1 in most samples (Figure 14).

A.caudovittatus are commonly thought as a marine species (Wise *et al.,* 1994) although they are common in estuaries, particularly temperate estuaries (Allen and Swainston 1988) as early life stages and adults tend to avoid areas of low salinity (Wise *et al.,* 1994). However, in the study by Wise *et al.,* (1994) the salinity of the study area only reached approximately 31 ‰, well below the minimum salinity recorded from the Dampier CPs (Figure 2). *A.caudovittatus* has been identified as a benthic predator that tends to feed on polychaete worms and small crustaceans (Wise *et al.,* 1994); however, from samples collected from the Dampier CPs, large *A.caudovittatus* were found to contain fishes and thus may be piscivorous is this unique environment. It may be that the benthic food sources that this species relies on are not present in the high salinities of the CPs and a switch to more common food sources has occurred, although more data are needed to confirm this observation. However, the presence of this species in salinities approaching or exceeding 100 ‰ greatly extends the knowledge of the ability this species to cope with high salinities.

The catch rate of the gill nets, in terms of CPUE in biomass, varied between 0 $kg.h^{-1}$ and 26.0 $kg.h^{-1}$ with the highest average catches recorded from CP 1 (Figure 10). Extrapolation of the CPUE data to estimate total biomass within the CPs indicates that between approximately 66 – 105 tonnes (high estimate) of fish were present in the surveyed CPs (8 –17 tonnes, low estimate, Table 6). Although a range of estimates of total biomass were generated, these data are of a similar order of magnitude to the estimated landings by the Pilbara inshore netting fishery between 1985 and 1997 (19 – 86 tonnes in the West Zone and 8 – 43 tonnes in the East Zone, (Stephenson and Mant, 1998)). [It should be noted that the reported catch in the Pilbara inshore netting fishery is only one component of the total biomass, as many by-catch species are also netted]. Although the species within the CPs differ from the species targeted in the Pilbara netting fishery (e.g. Barramundi, *Lates calcarifer*, and threadfin salmon (Family: Polynemidae), typically dominate the netting catches and were rare or absent within the CPs), the productivity of the ponds appears similar to that of the adjacent fishery and indicates the relative level of fish resources within the CPs.

4.3 *Artemia* resources within the CPs

The species of *Artemia* collected from the Dampier Salt CPs was identified as *A.franciscana*, the same species as in Port Gregory, and a major species cultured to supply aquaculture industries. *Artemia* are encouraged in solar salt ponds as they assist in maintaining water clarity, increasing evaporation rates and therefore increasing the efficiency of salt production (Thomas 1991, Tyler 1996). Further, *Artemia* are used in aquaculture facilities as the first exogenous source of food for many species of larvae fishes and invertebrates (Sorgeloos *et al.,* 1986; Hoff and Snell 1987). There were 251 269 (± 12 018) cysts.g^{-1} in the sample obtained from the Dampier Salt CPs, similar to number of cysts.g^{-1} reported at other locations. However, the cysts were slightly smaller than cysts from Port Gregory (another site within Australia) (240.48 µm compared to 262.19 µm), although this difference was not significant. Smaller cysts are preferred in aquaculture as these will hatch into smaller larvae and thus can be used to feed younger larvae (S. Kolkovski, pers. comm.). The hatching of the cysts was 87.13 % after 24 hours at 28 ºC, a standard measure, and hatching was synchronised.

The levels of two critical fatty acids (FA) were examined from the *Artemia* cysts collected from the Dampier Salt fields. The level of eicosapentaenoic acid (EPA) was relatively low at 8.6 % but still within the range of levels in *Artemia* from other parts of the world (0.3 – 14.6 %). Docosahexaenoic acid (DHA) was also relatively low at 0.1% as was the summed levels of highly unsaturated fatty acids (HUFA) in the sample (9.3 %) when compared to levels in *Artemia* from other parts of the world (15.2 %). These FAs are important in the nutrition of cultured fishes as they cannot be manufactured by the fish (i.e. essential fatty acids) and thus may become the limiting factor of growth and survival of larval fishes and invertebrates.

Although the characteristics of the *Artemia* sample showed positive prospects for larval fish culture, the sample itself may have been of higher quality if collected and stored differently. Nonetheless, the overwhelming positive results of the quality and hatching rate of the sample indicate that the *Artemia* in the CPs has a high potential as an aquaculture candidate.

5.0 Application of results

From the above discussion, the Dampier Salt CPs may be potentially a large source of aquatic production in the Pilbara region. The fish resources within the CPs exceeded 60 tonnes throughout the year and exceeded 100 tonnes in May 2000. Although the number of species is lower than that typically recorded in other tropical estuaries, a large number of recreational and/or commercial species were present, sometimes in large numbers. *Artemia* within the CPs also show potential for exploitation. It should be noted that the exploitation of any species within the CPs assumes that the breeding stocks of all species are maintained in adjacent coastal waters.

The following are examples of the options for the PDC and Dampier Salt to better utilise and/or manage these resources. These options should not be seen as all possible options, nor should they be considered as mutually exclusive. Further, many of these options may provide opportunities for the indigenous involvement among Dampier Salt, the Pilbara Development Commission and the Indigenous groups adjacent to the CPs.

5.1 Redesigning CP OA to allow fish escapement back into adjacent creeks

Many of the species of fishes recorded from the CPs are unlikely to mature or breed in the CPs. Thus, many of these species have recruited into the CP system via the pumping process. From observations and anecdotal accounts from Dampier Salt staff, many of these fishes in CP OA aggregate around the pumping stations during the pumping process. This is most likely due to feeding opportunities created by small fishes being pumped into the system and is likely to be a learned response. However, this behaviour can be exploited to reduce fish biomass within the CPs, especially of predatory fishes.

For example, a solar salt producer at Shark Bay has installed a simple system to encourage fishes to leave the first pond. A bund wall inside the first pond, enclosing an area of approximately 1 ha, has been constructed. The wall is lower than the external bund walls and is overtopped by water during pumping. This allows fishes within the first pond to move towards the pumps, into the 1 ha area. However, when pumping ceases, the water level within the first pond reduces and the water (and fishes) within the 1 ha area becomes isolated from the rest of the pond. This water drains out of the system back into adjacent waters via large diameter culverts fitted with one-way valves. Fishes in this 1 ha area are also allowed to escape the system back into adjacent waters via this culvert, allowing these fishes to contribute to local recreational and commercial fisheries.

The success of allowing fishes to escape can be further enhanced by screening the connections between adjacent CPs. Most of the CPs are linked by a single channel only a few metres wide. Installing screens (for example, galvanised or stainless steel mesh of approximately 50 x 50 mm or smaller) would restrict most fishes to only CP OA, thus reducing fish presence and therefore deaths in other CPs.

5.2 Exploitation of the fish resources within the CPs

Given the large biomass of fishes within the CPs and anecdotal knowledge of movement and concentrations of fish by staff of Dampier Salt, the fishes within the CPs could easily be harvested. For example, large fishes tend to aggregate around the pumping stations during pumping events, whether this be due to movement into a stream of water or associating the sound of the pumps with an input of new prey items. A range of fishing gears could be employed to harvest fishes within the CPs. Gill nets and other unbaited, passive gears are suggested as these gears do not interfere with the benthos (critical in maintaining water quality (Burnhard 1991)) or add nutrients to the CPs, potentially increasing the nutrient levels (e.g. baited fish traps). Although a viable option in terms of harvesting fishes, the fishing gears are not targeted for specific species and thus non-targeted species of low economic value, such as *Elops hawaiiensis*, and species important to the maintenance of water clarity, such as *Chanos chanos*, may also be captured. However, some of these species may be important to local indigenous groups. Further, some of these low-value species may have a market within the Asian communities of the Pilbara and other areas. The training of indigenous persons to harvest fish from within the CPs may be possible through a regional traineeship and would enhance the relationship between Dampier Salt and local indigenous groups. The Department of Fisheries should be consulted if this option is to be pursued.

5.3 Selective harvesting of species not contributing to water clarity

Although the CPs themself account for most of the area of the Dampier Salt concentrator complex, there are several areas of extensive channel and areas outside of the main areas of the CPs (Figure 1). In these areas, large concentrations of estuarine cod, *Epinephelus coioides*, mullet, *Valamugil buchanani* (channels) and bream, *Acanthopagrus latus* (side area), exist in relatively small areas. Further, the presence of some of these species, like *V.buchanani*, concentrate at certain times of the year (pers. obs.), most likely as a result of these species attempting to migrate against water flow to spawn and becoming trapped in the channel. In these areas, other gear types like haul nets and traps could be used without a risk to the benthos of the main CPs. Further, the three species identified above are of relatively high commercial value.

However, two points should be noted. Firstly, most of the fishes within the CPs are likely to be pumped from the creeks and are not a result of within-CP reproduction. Therefore, the "ownership" of these fishes may be with the State. Therefore, any fishing operations must be developed with the Department of Fisheries prior to harvesting.

5.4 Aquaculture of selective fish species

An alternative to harvesting fishes from the CPs is by the construction of dedicated aquaculture facilities. For example, Dampier Salt could chose to build dedicated ponds suitable for particular species of fish. Initially, the viability of aquaculture could be tested with fish harvested from the CPs at a small size and on-grown. In the long-term however, broodstock would need to be used to generate fingerlings via an aquaculture facility. The species selected would need to be based on current aquaculture technologies, knowledge of the biology and requirements of the species, current and potential markets, transport and many other considerations. It should be noted that traineeships may be available for training local people in aquaculture, especially indigenous persons. The Aquaculture Program of the Department of Fisheries can assist in many of these areas.

5.5 Harvesting of *Artemia*

The harvesting of *Artemia* is common practice from large solar salt fields throughout the world (Sorgeloos *et al.,* 1986) and production rates of 3.93 $kg.ha^{-1}.yr^{-1}$ have been reported (Gopalakrishnan and Shenoy 1998). This due to the life-history of *Artemia* and the relationship of reproduction with salinity. *Artemia* will breed and produce free swimming nauplii over a wide range of salinities (Hoff and Snell 1987, Tyler 1996). However, in higher salinities (greater than approximately 80 - 90 ‰ (Tyler 1996)), resting stage cysts become positively buoyant and easily observed. Further, these floating cysts will be inert until water of an appropriate lower, salinity (less than approximately 80 ‰ (Tyler 1996)) is encountered.

As water in the Dampier Salt CPsμ moves through the CPs into ponds with higher salinities (> 120 ‰), cysts will appear on the water surface. Cysts can be concentrated into surface slicks due to wind action, or be blown onto banks of the CPs (Sorgeloos *et al.,* 1986). Cysts in slicks can be harvested with small boats equipped with booms of fine mesh, while on banks the cysts can be collected by hand but are often mixed with sand and other debris and must be cleaned. The harvesting of cysts can be managed when slicks and/or banks of cysts are visible to staff. This is likely to occur throughout the year. However, during periods of intense rain, as was experienced in May 2000 and January 2001 (Figure 2), cysts may hatch in all CPs due to the influence of rain reducing the salinity of the water within the CPs, at least on the surface. Thus, harvesting is likely to be limited in post-rainfall periods, especially after cyclonic rains (approximately one in three to four years) and production is likely to be unreliable.

5.6 Aquaculture of *Artemia*

Alternatively, *Artemia* can be cultured intensively in purpose-built facilities. Although requiring capital investment and staff with appropriate skills, the benefits of culture facilities are that production can be programmed and is more predictable than wild harvesting, and the product can be produced in a clean state. More details of culture are available in culture manuals (e.g. Sogeloos *et al.,* 1986, Hoff and Snell 1987) and from the Department of Fisheries. However, the skills to operate such a facility and infrastructure are not currently available within the Pilbara and are still in their experimental stage in Western Australia.

5.7 Management of the fish based nutrient (FBN) levels within the CPs

The data collected in the current study can be used to model the nutrient status of the ponds, at least those associated with fish biomass (Table 7). Although high levels of FBN were found in the CPs 0A – 3 at all times, the distribution of FBN within the sampled CPs varied at different times of the year. Generally, the levels of FBN were similar within a CP throughout the sampling period; CP 1 always had higher levels than CP 0B which in turn had higher levels than CP 0A. However, while the lowest levels in both CPs 0A and 0B were recorded in Winter 2000, the lowest levels in CP 1 were in Autumn. Further, extreme fluctuations in FBN were recorded from CPs 2 and 3, varying between zero biomass (CP 3, Spring 2000), to 8.1 tonnes (CP 3, Autumn 2000).

Variations in the levels of FBN within CPs is a result of fish recruitment, fish growth, fish movement and fish deaths. It is likely that reduced levels of FBN in CPs of higher salinities are a result of fish deaths during periods of the year when salinities are extreme. Although no fish deaths were observed during any of the four sampling periods, fish deaths have been recorded by Dampier Salt staff. Given the information presented in table 7, plus the information on salinity and other water parameters collected by staff of Dampier Salt, a re-examination of fish mortality records can now be undertaken (i.e. date of occurrence of fish death versus salinity, temperature and dissolved oxygen levels within each pond). This would reveal times and CPs when fish deaths are likely to occur and destocking of the CPs can occur prior to fish death.

Further research may indicate the optimum FBN levels to maintain to reduce the size and/or occurrence of fish deaths. Further, a re-examination of Dampier Salt records may identify the species that typically experience mortalities, and the water conditions when the mortality events occur. Salinity-sensitive species may be confined to CPs which do not experience extreme salinities (via screens) or mortality-prone fishes may be specifically removed shortly after recruitment into the ponds. This would be achieved by knowing the biology and ecology of target species, such as their salinity preferences, recruitment periods and movement patterns within the CPs.

6.0 Discussion of commercial options

The options outlined above are all possible in the Pilbara region in conjuction with Dampier Salt. Further, the options have a range of start-up times from almost immediately (e.g. harvesting) to several years (e.g. aquaculture of selected fish species) (Table 9). Table 9 also highlights some of the skills and infrastructure associated with the commercialisation of each option. It should be noted that for at least some options the skill-base and/or infrastructure is not currently available in the Pilbara. Any potential commercial development should carefully consider the needs or a venture,prior to any investment, and the potential returns of a venture. However, one of the largest considerations remains to ownership of the fish resources within the CPs.

While Dampier Salt has permission to pump water into the CPs, and it is acknowledged that small fishes (e.g. larvae, small juveniles) are likely to enter with the water, the use of the commercial use of the fish resources is not currently permitted. While some species may breed within the CPs (e.g. small baitfishes), and therefore be considered self-sustaining, other species will not be able to complete their life-cycle within the CPs (e.g. estuarine cods). Thus, for any commercial exploitation of fish resources within the CPs, the issue of ownership must be addressed.

7.0 Future research options

The data collected in the current project has provided useful insights and options for the PDC and Dampier Salt and have extended the knowledge of fish resources within solar salt fields. More detailed management arrangements are, however, likely to require more detailed research.

For example, the timing of water pumping can be used to manage the FBN levels or species composition within the CPs. That is, the pumping of water could be increased when useful but (commercially or recreationally) unutilised species (e.g. milkfish, *Chanos chanos*) are recruiting into adjacent creeks. Conversely, the pumping of water could be restricted when undesirable species of fishes (e.g. those species with a history of mass deaths) are recruiting. This management option would require information on recruitment patterns in the adjacent tropical estuaries which may become available from a current collaborative research project being undertaken by the Department of Fisheries and Murdoch University. This management option may reduce the occurrence and cost of fish deaths as well as increase the numbers of desirable species within the CPs.

One of the most critical pieces of information that requires further work is to identify which, if any, species successfully reproduce CPs. From data collected in the present study, very few species appear to be self-recruiting within the CPs (Table 3). It is suspected that *Amniataba caudovittatus*, *Chanos chanos* and *Elops hawaiiensis* are likely to be at self recruiting within the CPs, although the pumping of at least some individuals of these species from the adjacent creeks is still possible. Further reproductive studies would not only identify the source of components of the fish fauna within the CPs, but will also provide information about the sustainability of certain species within the CPs (i.e. species that rely on recruitment from outside the CPs may be more vulnerable to harvesting and exploitation). From a salt field management perspective, this type of information would also impact on the management of nutrient levels within the CPs.

Movement within the CPs of various species of fishes is also unknown. Although many of the small species, such as *Ambassis vachelli*, are unlikely to move far throughout their relatively short life, larger species like *Elops hawaiiensis* and *Scomberoides commersonnianus* are capable of covering large distances in relatively short periods of time. This may allow movement at least one-way throughout the CP system and will determine the range of CPs in which harvesting is to be undertaken. Further, if the movement is related to reproduction (e.g. an attempt to find water of lower salinities), then the movement and distribution of the species, coupled with information about the spawning season of selected species, will provide information about the likely location of large numbers of fishes (e.g. at the gates between ponds), providing opportunities for harvesting of these species.

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10.0 Tables

Table 1. Dimensions of CPs used to calculate fish numbers and biomasses. Pond areas were supplied by Dampier in hectares and converted into m^2. Perimeters were calculated from an aerial photograph of the CPs.

Pond	Area (ha)	Area (m^2)	Perimeter (m)
OA	534	5 340 000	12 000
OB	1066	10 660 000	32 000
1	1225	12 250 000	15 500
2	1141	11 410 000	14 000
3	797	7 970 000	12 000
4	629	6 290 000	10 000
5	642	6 420 000	10 000
6	411	4 110 000	9 000
7	381	3 810 000	8 500
8	447	4 470 000	8 000
Totals	7273	72 730 000	131 000

Table 2. Species of fishes captured during the project, with information on value category, distribution by biomass and numbers within the sampled concentrator ponds.

Scientific name	Common name	Value category	Estimated numbers	Estimated biomass	Total numbers
Allanetta mugiloides	Spotted hardyhead	5	OB	OB	11579
Apogon ruppellii	Gobblyguts	5	1	OA	6660
Ilisha striatula	Banded Ilisha	4	OB	OB	3634
Stolephorus spp	Anchovy	4	1	OB	2172
Gerres oyena	Common silver biddy	4	OA	OA	1605
Arramphus sclerolepis	Snub-nosed garfish	4	OB	OB	889
Amnitaba caudovittatus	Yellowtail trumpeter	4	OB	OB	725
Elops hawaiiensis	Giant herring	4	1	1	340
Sillago vittata	Western school whiting	1,4	OA	OA	266
Acanthropagrus latus	Western yellowfin bream	1,2	OA	OA	147
Chanos chanos	Milkfish	1,4	OB	1	147
Valamugil buchanani	Blue tail mullet	1,2	OB	OB	130
Sillago analis	Golden-lined whiting	1,4	OA	OB	128
Leiognathus equulus	Common ponyfish	4	OA	OB	112
Scomberoides commersonnianus	Queenfish	1,4	OB	OB	110
Leiognathus bindus	Orangefin ponyfish	4	OB*	OB*	83
Ambassis vachellii	Telkara perchlet	4	OB	OA	33
Arius thalassinus	Giant salmon catfish	4	OA	OA	28
Platycephalus indicus	Bartail flathead	1	OA	OA	28
Bathygobius fuscus	Common goby	4	1	OA	24
Dexillichthys muelleri	Tufted sole	3,4	1	1	24
Selenotoca multifasciata	Striped butterfish	3,4	OB	1	16
Epinephelus coioides	Orange spotted grouper	1,2,6	OA	OA	8
Gnathanodon speciosus	Golden trevally	1,2,6	OA	OA	7
Pelates quadrilineatus	Trumpeter	4	OA*	OA*	7
Scomberomorous semifasciatus	Broad-barred spainish mackerel	1	OA*	OA*	5
Caranx ignobilis	Giant trevally	1,2,6	OA,OB	OB	4
Pomadasys kaakan	Spotted javelinfish	1	OA*	OA*	4
Sillago sihama	Northern whiting	1	OA*	OA*	4
Anodontostoma chacunda	Gizzard shad	4	OB*	OB*	3
Polydactylus plebius	Northern threadfin	1,2	Creek*	Creek*	3
Syphraena jello	Giant seapike	1,4	OA	OA	3
Cymbacephalus nematophthalmus	Fringe-eyed flathead	1	OA*	OA*	2
Epinephelus malabaricus	Malabar grouper	1,2,6	OA,1	OA	2
Lates calcarifer	Barramundi	1,2,6	1*	1*	2
Lutjanus argentimaculatus	Mangrove jack	1,6	OA,1	1	2
Terapon puta	Three-lined grunter	4	OB*	OB*	2
Tylosurus crocodilus	Crocodilian longtom	5	1,OB	1	2
Acanthopagrus palmaris	Black bream	1,2	OA*	OA*	1
Platycephalus endrachtensis	Bartail flathead	1	OB*	OB*	1
Scatophagus argus	Spotted scat	3,4	OA*	OA*	1
Siganus lineatus	Goldern-lined spinefoot	3,4	OA*	OA*	1

Value category
1-Edible fish
2-Seed for on-growing
3-Ornamental fish
4-Fish with low economic value
5-Fish with no economic value
6-Fish with indigenous value

Table 3. Diet and reproductive information for common species of fishes collected from the Dampier Salt concentrator ponds.

Scientific name	Common name	Diet	Reproduction	Gut sampled	Gonads sampled
Amniataba caudovittatus	Yellowtail trumpeter	Piscivorous; one fish found baitfish in gut	Male and female mature and immature	27	27
Elops hawaiiensis	Giant Herring	Piscivorous; seven fish found with small baitfish in gut including small *Amniataba sp.*	Male and hermaphrodite mature and immature	32	32
Sillago vittata	Western school whiting	Crustaceans and worms	Female immature	1	1
Acanthopagrus latus	Western yellowfin bream	Piscivorous; fish found with ~100-200 10mm prawns in gut	Female mature, male semi-mature and immature	27	27
Chanos chanos	Milkfish	Cyanobacteria, algae, small benthic invertebrates, fish eggs and larve	Male and female immature	None; diet from literature	2
Valamugil buchanani	Blue tail mullet	Algae, diatoms, detritus and crustaceans	Mainly female mature (full of eggs) and some male immature	None; diet from literature	24
Sillago analis	Golden-lined whiting	Crustaceans and worms	Full females and immature fish	None; diet from literature	7
Scomberoides commersonnianus	Queenfish	Piscivorous; prawns found in gut	Females with visible eggs and immature males	5	5
Platycephalus indicus	Bartail flathead	Piscivorous; small bones found in gut	Female mature and full of eggs also semi-mature females	3	3
Epinephelus coioides	Orange spotted grouper	Piscivorous; large variety of baitfish in guts	Males and females and hermaphrodites	10	10
Gnathanodon speciosus	Golden trevally	Piscivorous; gut contained small baitfish	Not sampled	1	1
Scomberomorous semifasciatus	Broad-barred spainish mackerel	Piscivorous; gut contained three *Ilisha sp.*	Male immature	1	1
Caranx ignobilis	Giant trevally	Piscivorous; gut contained small baitfish	Male and female mature	3	3
Sillago sihama	Northern whiting	Crustaceans and worms	Immature females	4	4
Epinephalus malabaricus	Malabar grouper	Piscivorous; large variety of baitfish in guts	Male and hermaphrodite	2	2
Lates calcarifer	Barramundi	Piscivorous; small baitfish in guts	Male mature	1	1
Lutjanus argentimaculatus	Mangrove jack	Piscivorous; fish and small prawns in gut	Female mature	1	1
Tylosurus crocodilus	Crocodilian longtom	Piscivorous; gut contained many small fish bones	Mature female	1	1

Table 4. Abundance and biomass rankings of fishes recorded from the CPs.

4 a. Seine Samples

4 a.1 Data from CP 0A

Species	**Rank by weight**				**Rank by number**			
	Trip				**Trip**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Gerres oyena	1	9	12	2	1	9	7	3
Sardine	9	10	-	-	2	3	-	-
Arramphus sclerolepis	3	6	5	7	3	5	4	4
Leignathus equulus	10	13	-	-	4	11	-	-
Ilisha striatula	11	2	-	-	5	1	-	-
Acanthopagrus palmaris	-	-	-	8	-	-	-	5
Siganus lineatus	-	-	-	6	-	-	-	12
Sillago analis	7	-	8	10	6	-	6	6
Ambassis sp.	13	12	-	-	7	8	-	-
Amniataba caudovittatus	6	3	11	12	8	4	11	8
Acanthropagrus latus	5	1	3	1	9	7	9	5
Allanetta mugiloides	15	7	6	4	10	2	2	1
Valamugil buchanani	14	5	9	11	11	12	5	9
Apogon ruppellii	16	11	2	3	12	6	1	2
Dexillichthys muelleri	-	-	13	13	-	-	13	11
Pelates quadrilineatus	-	-	10	-	-	-	8	-
Platycephalus indicus	4	-	1	5	13	-	10	14
Bathygobius fuscus	18	14	-	14	14	14	-	10
Cymbacephalus nematophthalmus	12	-	-	-	15	-	-	-
Sillago vittata	-	-	4	9	-	-	3	7
Epinephelus coioides	2	8	-	-	16	10	-	-
Sillago sihama	17	-	7	-	17	-	12	-
Arius thalassinus	-	4	-	-	-	13	-	-
Scatophagus argus	8	-	-	-	18	-	-	-

4 a.2 Data from CP 0B

Species	Rank by weight				Rank by number			
	Trip				Trip			
	1	2	3	4	1	2	3	4
Gerres oyena	2	-	10	5	4	-	6	3
Sardine	14	8	-	6	3	4	-	2
Arramphus sclerolepis	6	1	3	3	5	3	4	4
Leiognathus bindus	11	-	-	-	7	-	-	-
Leionathus equulus	17	-	-	-	10	-	-	-
Tylosurus crocodilus	-	-	8	-	-	-	8	-
Ilisha striatula	9	4	7	11	1	2	2	5
Sillago analis	13	10	-	10	15	10	-	7
Selenotoca multifasciata	16	-	-	-	16	-	-	-
Ambassis sp.	-	-	9	-	-	-	5	-
Amniataba caudovittatus	4	7	1	-	6	6	3	-
Acanthropagrus latus	8	3	2	1	13	5	7	9
Platycephalus endrachtensis	-	6	-	-	-	9	-	-
Allanetta mugiloides	15	5	4	4	2	1	1	1
Terapon puta	-	-	-	12	-	-	-	11
Valamugil buchanani	10	-	-	9	11	-	-	8
Apogon ruppellii	18	11	11	15	14	8	10	14
Elops hawaiiensis	7	-	-	-	8	-	-	-
Chanos chanos	5	-	-	7	9	-	-	13
Dexillichthys muelleri	19	-	13	14	18	-	13	15
Scomberoides commersonnianus	3	9	5	-	19	11	12	-
Platycephalus indicus	1	2	6	2	17	7	9	12
Bathygobius fuscus	-	-	-	13	-	-	-	10
Sillago vittata	12	-	12	-	12	-	11	-

4 a.3 Data from CP 1.

Species	Rank by weight				Rank by number			
	Trip				Trip			
	1	2	3	4	1	2	3	4
Gerres oyena	-	-	9	8	-	-	7	4
Sardine	6	9	-	6	2	3	-	1
Arramphus sclerolepis	8	8	6	4	7	10	6	5
Lates calcarifer	2	-	-	2	11	-	-	11
Lutjanus argentimaculatus	-	-	2	-	-	-	10	-
Tylosurus crocodilus	4	-	-	-	10	-	-	-
Ilisha striatula	11	-	3	5	4	-	1	2
Sillago analis	10	-	-	9	12	-	-	6
Selenotoca multifasciata	3	6	-	-	8	7	-	-
Amniataba caudovittatus	7	5	5	10	5	4	4	7
Acanthropagrus latus	5	1	-	-	13	5	-	-
Allanetta mugiloides	9	7	7	-	3	2	3	-
Valamugil buchanani	-	2	-	-	-	8	-	-
Apogon ruppellii	1	4	4	7	1	1	2	3
Elops hawaiiensis	-	3	1	3	-	9	5	10
Chanos chanos	-	-	-	1	-	-	-	8
Dexillichthys muelleri	12	-	8	12	6	-	9	12
Bathygobius fuscus	13	10	-	11	9	6	-	9
Sillago vittata	-	-	10	-	-	-	8	-
Dexillichthys muelleri	19	-	13	14	18	-	13	15
Scomberoides commersonnianus	3	9	5	-	19	11	12	-
Platycephalus indicus	1	2	6	2	17	7	9	12
Bathygobius fuscus	-	-	-	13	-	-	-	10
Sillago vittata	12	-	12	-	12	-	11	-

4b. Gill net Samples

4 b.1 Data from CP 0A

Species	**Rank by weight**				**Rank by number**			
	Trip				**Trip**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Valamugil buchanani	1	-	-	-	1	-	-	-
Elops hawaiiensis	2	1	4	5	3	1	4	4
Scomberoides commersonnianus	3	3	1	1	7	6	2	1
Gnathanodon speciosus	4	-	3	-	4	-	3	-
Epinephelus coioides	5	-	5	-	6	-	5	-
Scomberomorous semifasciatus	6	-	-	-	2	-	-	-
Lutjanus argentimaculatus	7	-	-	-	8	-	-	-
Chanos chanos	-	3	2	2	-	4	1	2
Pomodasys kaakan	-	3	5	4	-	5	6	3
Arius thalasinus	-	-	-	3	-	-	-	6
Platycephalus indicus	8	2	-	-	5	2	-	-

4 b.2 Data from CP 0B

Species	**Rank by weight**				**Rank by number**			
	Trip				**Trip**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Valamugil buchanani	3	-	1	4	3	-	3	5
Elops hawaiiensis	2	2	1	3	2	2	2	3
Scomberoides commersonnianus	1	1	1	1	1	1	4	2
Gnathanodon speciosus	-	3	-	-	-	3	-	-
Leiognathus bindus	-	-	4	-	-	-	7	-
Chanos chanos	4	3	2	2	4	4	1	1
Caranx ignobilis	-	-	4	4	-	-	5	4
Anodontostoma chacunda	-	-	3	-	-	-	6	-
Arius thalasinus	5	-	-	-	5	-	-	-
Platycephalus indicus	-	3	-	-	-	5	-	-

4 b.2 Data from CP 1

Species	Rank by weight				Rank by number			
	Trip				Trip			
	1	2	3	4	1	2	3	4
Valamugil buchanani	-	2	-	-	-	3	-	-
Elops hawaiiensis	1	1	1	1	1	1	1	2
Scomberoides commersonnianus	3	4	3	3	3	4	3	4
Gerres oyena	4	-	-	-	4	-	-	-
Chanos chanos	2	3	2	1	2	2	2	2
Arius thalasinus	-	5	-	4	-	5	-	3

4 b.2 Data from CP 2

Species	Rank by weight				Rank by number			
	Trip				Trip			
	1	2	3	4	1	2	3	4
Sillago analis	-	-	-	1	-	-	-	1
Elops hawaiiensis	1	1	1	-	1	1	1	-
Amniataba caudovittatus	2	2	2	2	2	2	2	2

4 b.2 Data from CP 3

Species	Rank by weight				Rank by number			
	Trip				Trip			
	1	2	3	4	1	2	3	4
Valamugil buchanani	4	-	-	-	4	-	-	-
Elops hawaiiensis	1	1	-	-	1	1	-	-
Amniataba caudovittatus	2	-	-	1	2	-	-	1
Chanos chanos	3	2	-	-	3	2	-	-

Table 5. Estimates of the total numbers of fishes within each CP and the total number of fishes within the system for each sampling trip. The top number is the "High" estimate while the number in parentheses is the "Low" estimate. All error terms are 1 standard error.

Pond	Trip 1 Autumn 2000	Trip 2 Winter 2000	Trip 3 Spring 2000	Trip 4 Summer 2000
OA	66 483 ± 33 817 (64 624 ± 33 045)	153 901 ± 54 530 (152 396 ± 54 301)	162 422 ± 84 870 (160 740 ± 84 266)	177 367 ± 54 332 (175 044 ± 53 686)
OB	287 398 ± 34 017 (282 265 ± 32 104)	241 924 ± 98 614 (239 215 ± 97 889)	337 690 ± 84 923 (332 557 ± 83 990)	381 513 ± 82 910 (376 949 ± 82 291)
1	442 920 ± 87 698 (429 820 ± 86 069)	138 884 ± 59 367 (122 397 ± 58 067)	109 230 ± 26 664 (96 355 ± 83 990)	204 349 ± 85 231 (190 064 ± 84 394)
2	5 378 (329)	8 964 (5 453)	5 378 (329)	11 429 (700)
3	57 293 (3 509)	549 (334)	0 (0)	20 663 (1 266)
Total	859 472 ± 155 532 (780 547 ± 151 532)	544 299 ± 218 590 (514 595 ± 210 630)	614 719 ± 196 456 (589 981 ± 193 404)	795 321 ± 240 987 (744 022 ± 221 505)

Table 6. Estimates of the biomasses (kgs) of fishes within each CP and the total biomasses of fishes within the system for each sampling trip. The top figure is the "high" estimate while the figure in parentheses is the "low" estimate. All error terms are 1 standard error.

Pond	Trip 1 Autumn 2000	Trip 2 Winter 2000	Trip 3 Spring 2000	Trip 4 Summer 2000
OA	9 672 ± 5 084 (4 674 ± 2 564)	7 119 ± 522 (1 667 ± 522)	8 331 ± 3 238 (1 242 ± 419)	9 495 ± 2 080 (2 524 ± 869)
OB	18 160 ± 5 191 (7 346 ± 1 146)	7 768 ± 586 (2 207 ± 533)	18 414 ± 4 183 (4 862 ± 1 989)	16 364 ± 3 601 (4 692 ± 1 164)
1	24 902 ± 3 210 (2 329 ± 358)	39 721 ± 815 (3 582 ± 692)	39 204 ± 7 391 (5 094 ± 2 065)	37 179 ± 4 411 (3 953 ± 657)
2	19 524 (1 196)	11 228 (688)	108 (7)	3 615 (221)
3	32 676 (2 001)	719 (44)	0 (0)	794 (49)
Total	104 994 ± 13 486 (17 547 ± 4 068)	66 554 ± 5 950 (8 188 ± 1 989)	66 056 ± 14 813 (11 205 ± 4 473)	67 446 ± 13 092 (11 439 ± 2 874)

Table 7. Estimates (kgs) of nutrient levels associated with fishes within each CP and the total nutrients due to fishes within the system for each sampling trip. The top figure is the “high” estimate while the figure in parentheses is the “low” estimate. All error terms are 1 standard error.

Pond	Trip 1 Autumn 2000	Trip 2 Winter 2000	Trip 3 Spring 2000	Trip 4 Summer 2000
OA	2 418 ± 1 271 (1 169 ± 641)	1 780 ± 147 (417 ± 130)	2 083 ± 810 (310 ± 105)	2 374 ± 520 (631 ± 217)
OB	4 540 ± 1 298 (1 837 ± 287)	1 942 ± 146 (552 ± 133)	4 603 ± 1 046 (1 216 ± 497)	4 091 ± 900 (1 173 ± 291)
1	6 225 ± 802 (582 ± 90)	9 930 ± 204 (896 ± 173)	9 801 ± 1 848 (1 274 ± 516)	9 295 ± 1 103 (988 ± 164)
2	4 881 (299)	2 807 (172)	27 (2)	904 (55)
3	8 169 (500)	180 (11)	0 (0)	198 (12)
Total	26 233 ± 3 371 (4 387 ± 1 017)	16 639 ± 1 488 (2 047 ± 497)	16 514 ± 3 703 (2 801 ± 1 118)	16 862 ± 3 273 (2 860 ± 718)

Table 8. Results of fish sampling from Rod Cod Hole Creek and Ridley Creek during Summer 2001.

Creek	Sample Method	Species	Number	Mean length
Rock Cod Hole	Gill net	*Polydactylus plebius* (Northern Threadfin)	4	340 mm
	Gill net	*Arius thalassinus* (Giant Salmon Catfish)	2	460 mm
	Hook & Line	*Polydactylus plebius* (Northern Threadfin)	3	260 mm
	Hook & Line	*Arius thalassinus* (Giant Salmon Catfish)	15	400 mm
	Hook & Line	*Lutjanus argentimaculatus* (Mangrove Jack)	2	200 mm
Ridley	Hook & Line	*Lutjanus argentimaculatus* (Mangrove Jack)	2	250 mm
	Hook & Line	*Arius thalassinus* (Giant Salmon Catfish)	4	300 mm

Table 9. Comparison of options discussed in the application of results from the current study. This summary is simple to allow the identification of facilities and skills required to implement each option, the relative investment required and the relative return. Further information is available in the text.

Option	Description	Infrastructure needed	Skills needed	Time to Operating [1]	Anticipated Investment [1]	Anticipated Returns [1]	Comments
Redesigning CP OA to allow fish escapement back into adjacent creeks.	Construction of new wall and valves in two locations of CP OA.	New walls and valves	Construction. Likely to exist within Pilbara region.	12 Months	Medium	Nil. May be some cost savings due to reduced fish kills.	
Exploitation of the fish resources within the CPs.	Commercial fishing operations within the CPs.	Minimal, possibly access points for small boats	Commercial fishing. Present in Pilbara region.	Immediately	Minimal	Revenue from fish sales if markets exist.	Fishing operations could be restricted to channels and/or to the use of static, unbaited gears.
Selective Harvesting of Species not contributing to water clarity	Selective fishing operations within the CPs.	Minimal, possibly access points for small boats	Commercial fishing, Present in Pilbara region.	Immediately	Minimal	Revenue from fish sales if markets exist.	Selective fishing requires the targeting of certain species of fishes. May have some impact on non-target species.
Aquaculture of selective fish species	Commercial aquaculture.	Purpose built ponds and other facilities.	Commercial aquaculture skills for marine fishes. Currently limited in the Pilbara region.	Several years, depending on the species and strategy.	High	Potentially high if costs of production are minimised and high value species are produced. However, must compete with commercial fishery production.	A successful large scale marine fish aquaculture facility does not currently exist in Western Australia

Table 9. Comparison of options discussed in the application of results from the current study. This summary is simple to allow the identification of facilities and skills required to implement each option, the relative investment required and the relative return. Further information is available in the text. *(continued)*

Option	Description	Infrastructure needed	Skills needed	Time to Operating [1]	Anticipated Investment [1]	Anticipated Returns [1]	Comments
Harvesting of Artemia	Collection of Artemia from CPs.	Minimal, small boats, nets, cleaning and packing facilities, plus boat access into CPs.	Harvesting skills. Not currently present in the Pilbara region.	Immediately if/when conditions are correct.	Medium	Moderate when cysts are abundant. May be low during wet years.	Collection of cysts requires cysts to be cleaned and of high quality.
Aquaculture of Artemia	Commercial aquaculture.	Purpose built ponds and other facilities.	Commercial aquaculture skills for Atremia. Currently limited or absent in the Pilbara region.	Production may be rapid once facilities are constructed.	High	Potentially high if costs of production are minimised as there is a world shortage of high-quality Artemia.	A successful large scale Artemia aquaculture facility does not currently exist in Western Australia.
Management of the Fish Based Nutrient (FBN) Levels within the CPs.	Management of salt fields to reduce fish kills and reduce variations in nutrient levels.	Monitoring equipment (e.g. nets) and boats plus boat access into CPs.	Fish monitoring skills and regular sampling. May be present in the Pilbara region.	Immediately once equipment is on-site.	Low	Nil or minimal. Some fishes removed from the CPs may have a commercial value.	Similar to the selective harvesting of species not contributing to water clarity, but controlled by Dampier Salt.

Notes

1. Estimates are relative and are only to allow comparison among options

11. Figures

Figure 1. Aerial view of the concentrator ponds of Dampier Salt. Figure modified from LeProvost, Dames and Moore, 1996.

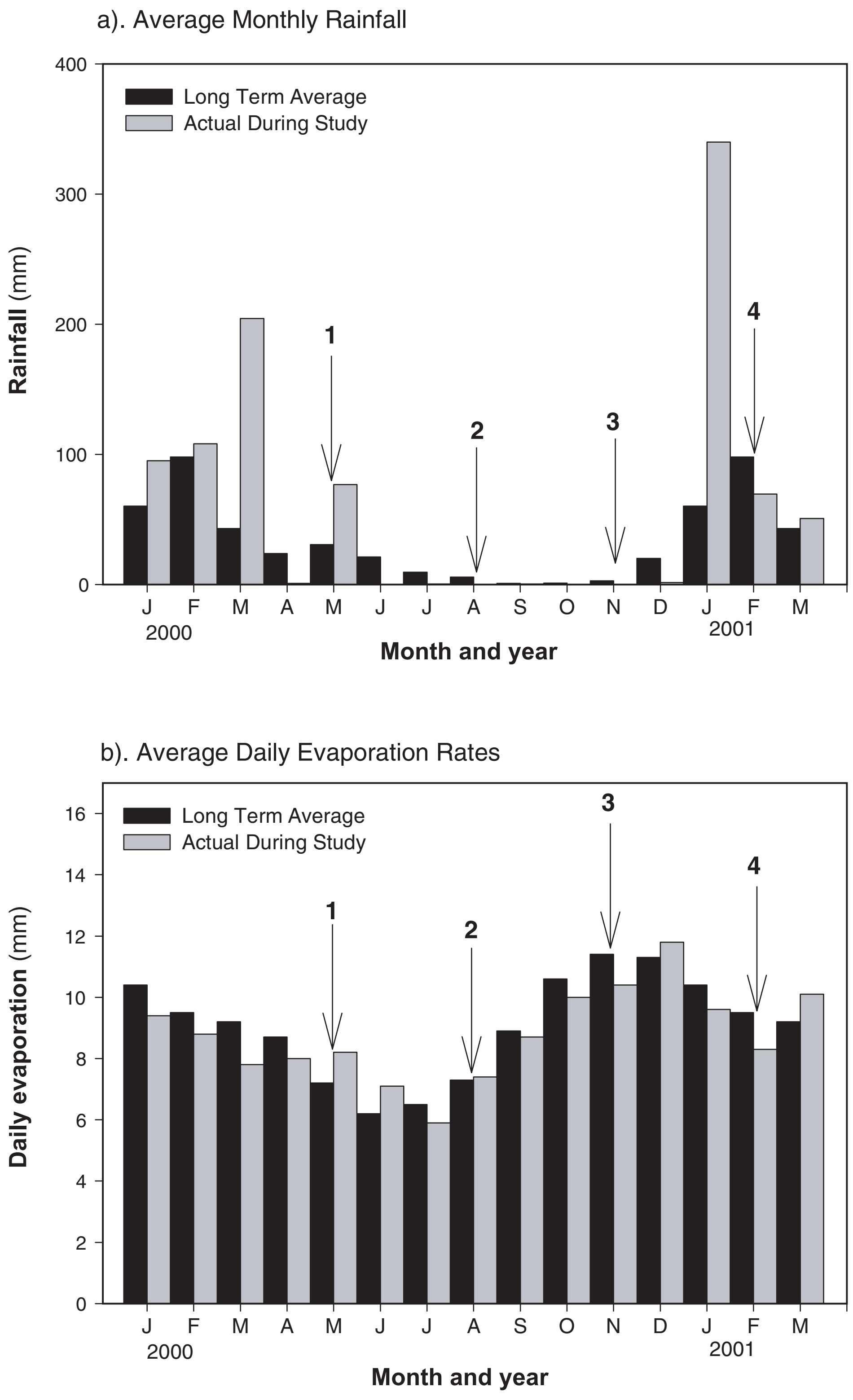


Figure 2. Average rainfall and daily evaporation rates for the Port Hedland region compared with actual levels during the study. (Arrows and numerals indicate sampling occasions)

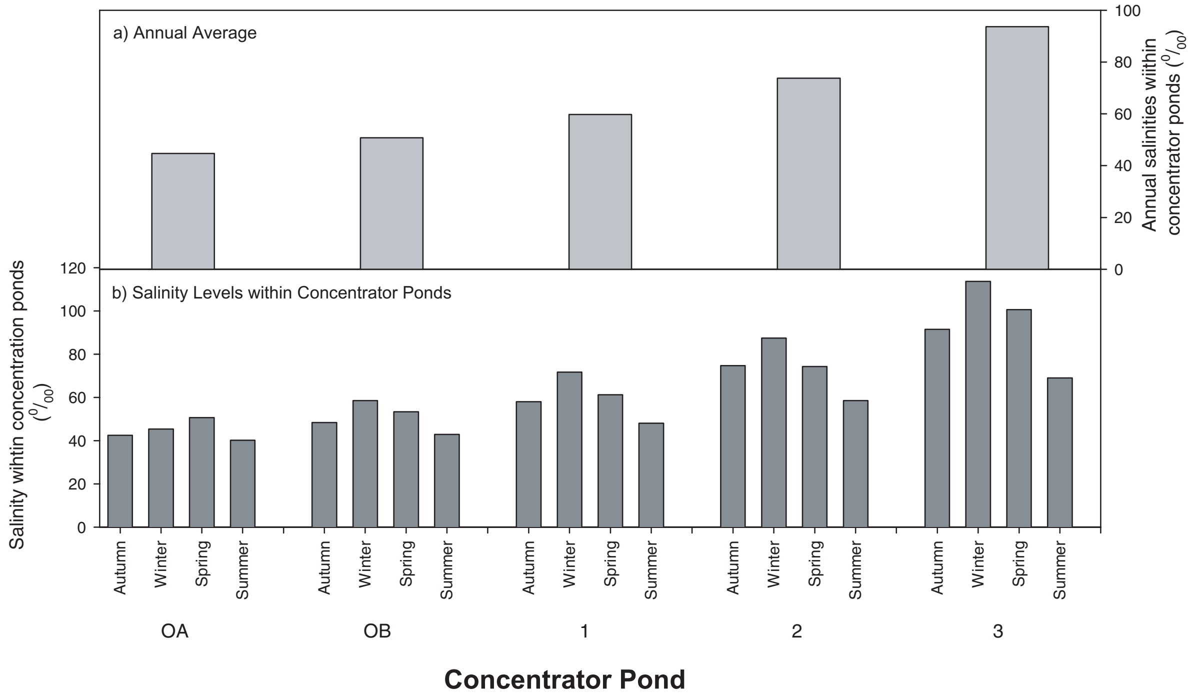


Figure 3. Salinity levels within concentrator ponds throughout the study.

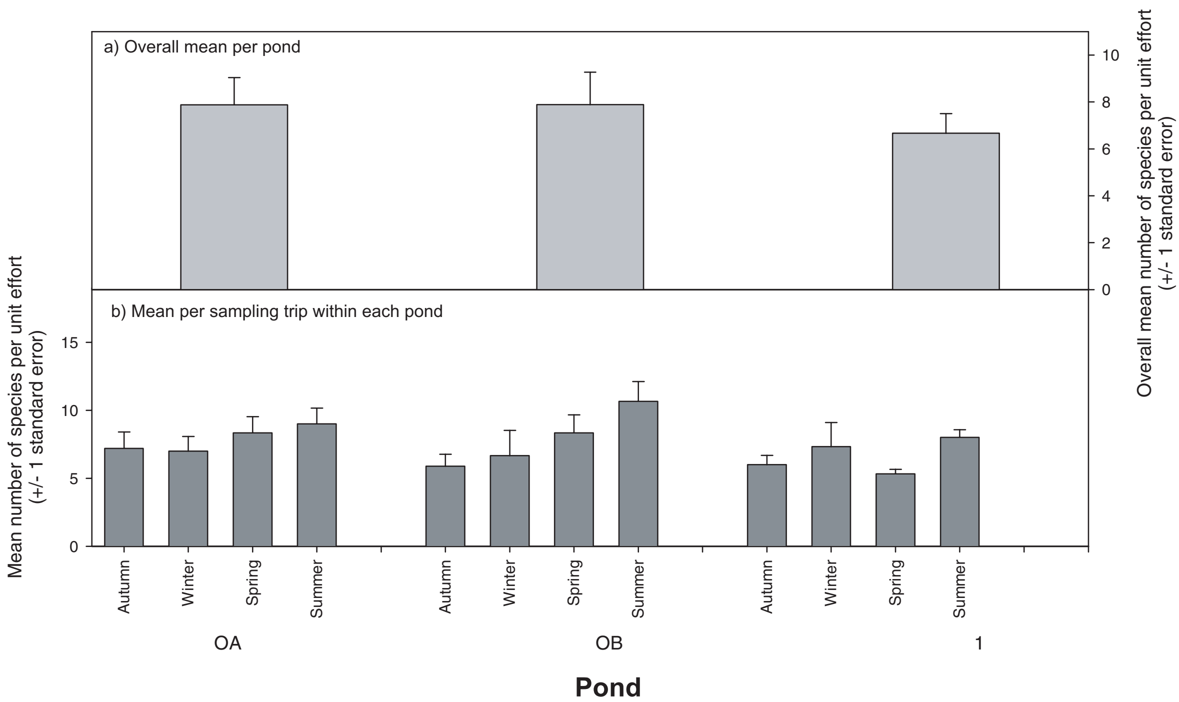


Figure 4. Mean number of fish species collected by seine nets within each concentrator pond.

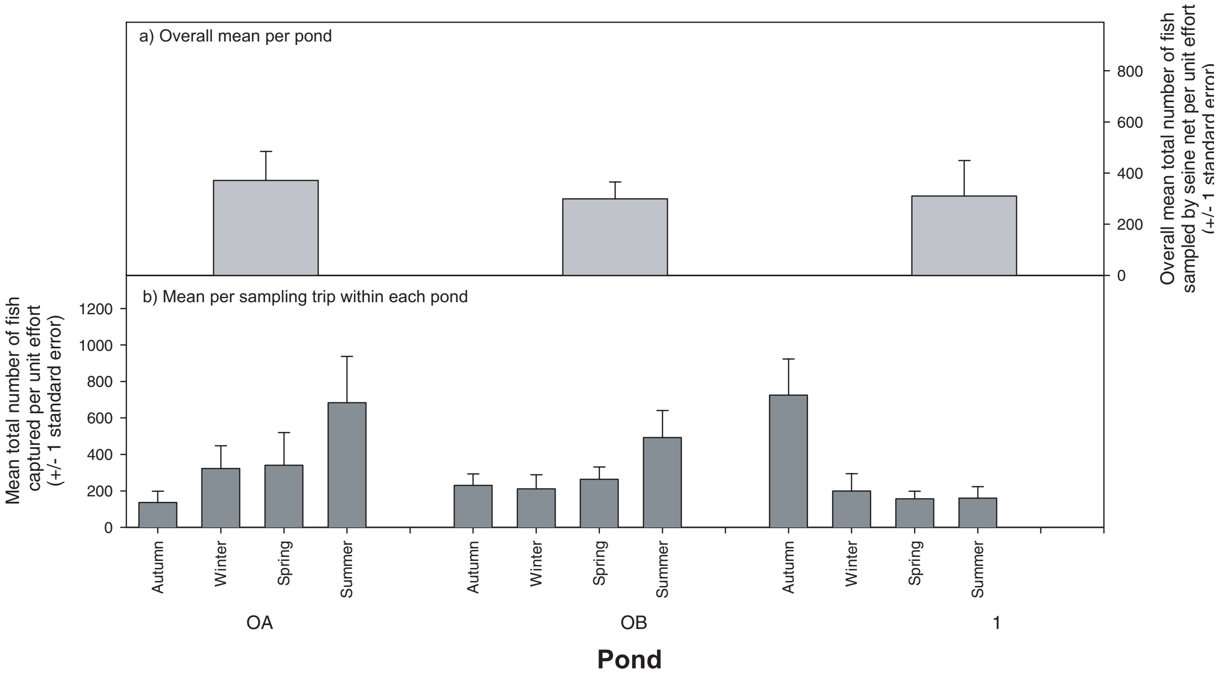


Figure 5 Mean total number of fish collected by seine nets within each concentrator pond.

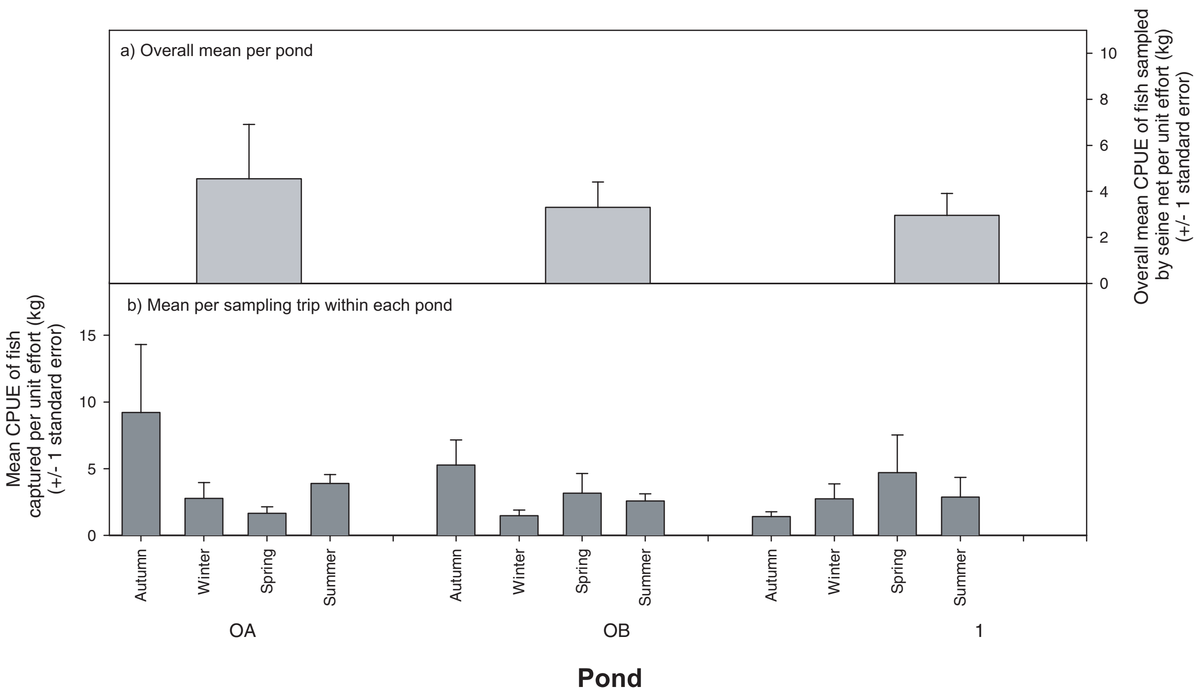


Figure 6. Mean CPUE of fish biomass collected be seine nets within each concentrator pond.

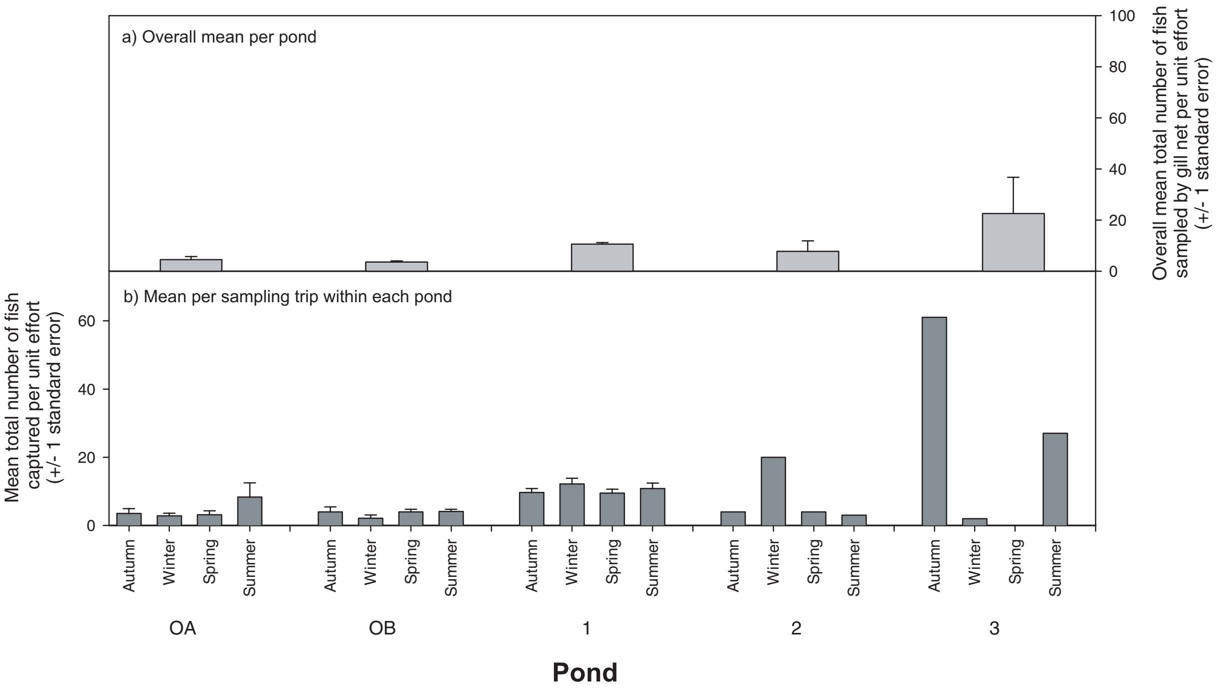


Figure 7. Mean total number of fish collected by gill nets within each concentrator pond.

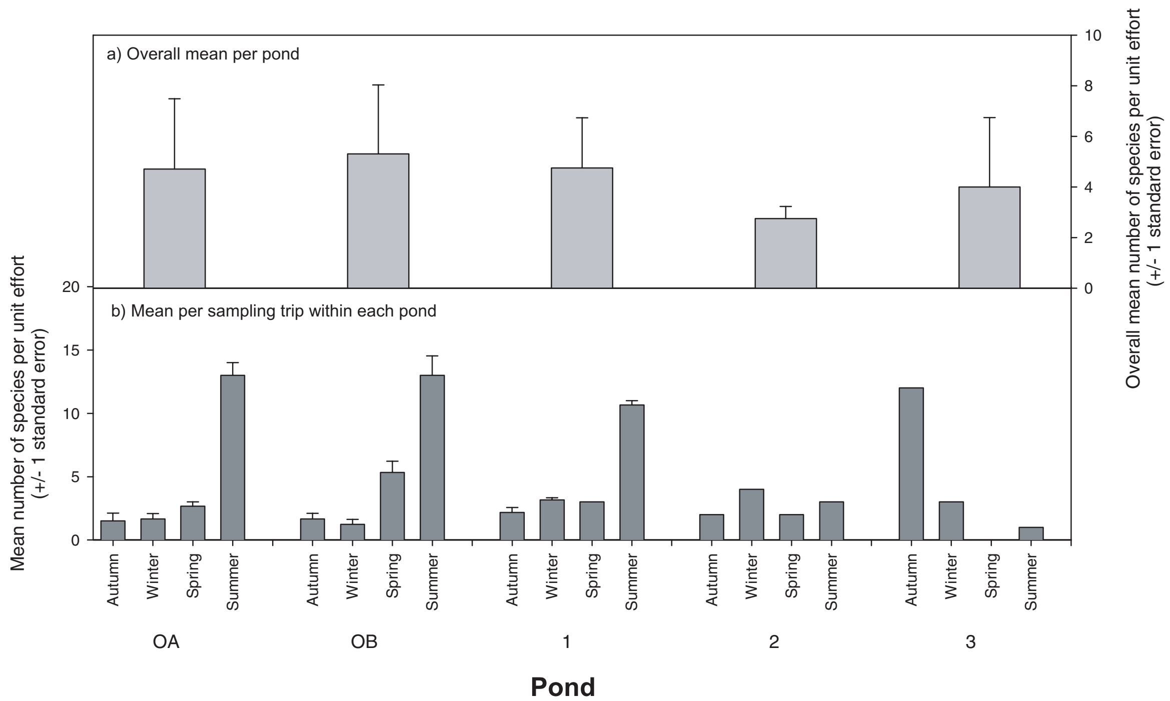


Figure 8. Mean number of fish species collected by gill nets within each concentrator pond.

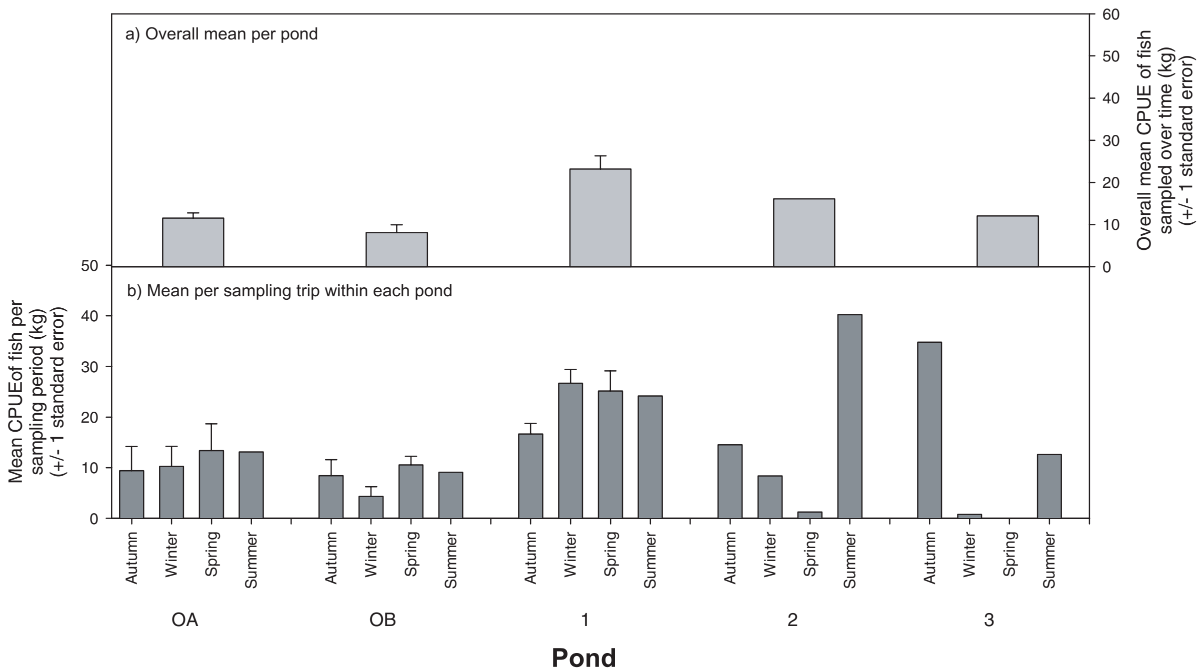


Figure 9. Mean CPUE of fish biomass collected by gill nets within each concentrator pond.

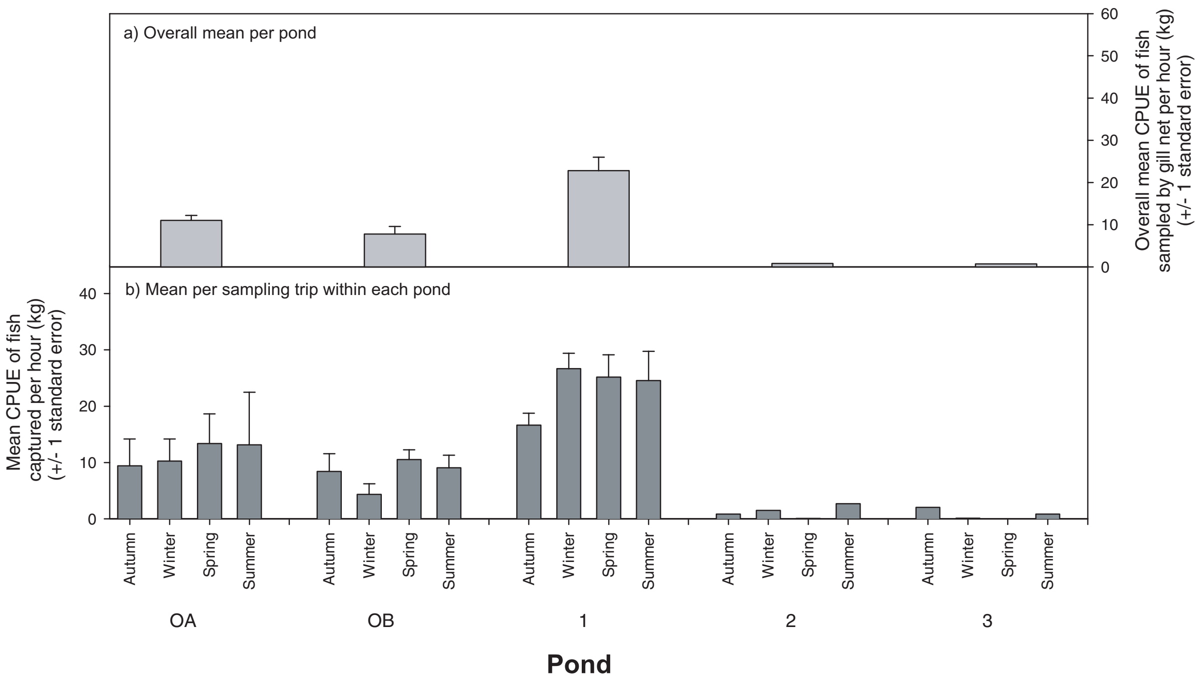


Figure 10. Mean CPUE of fish biomass per hour collected by gill nets within each concentrator pond.

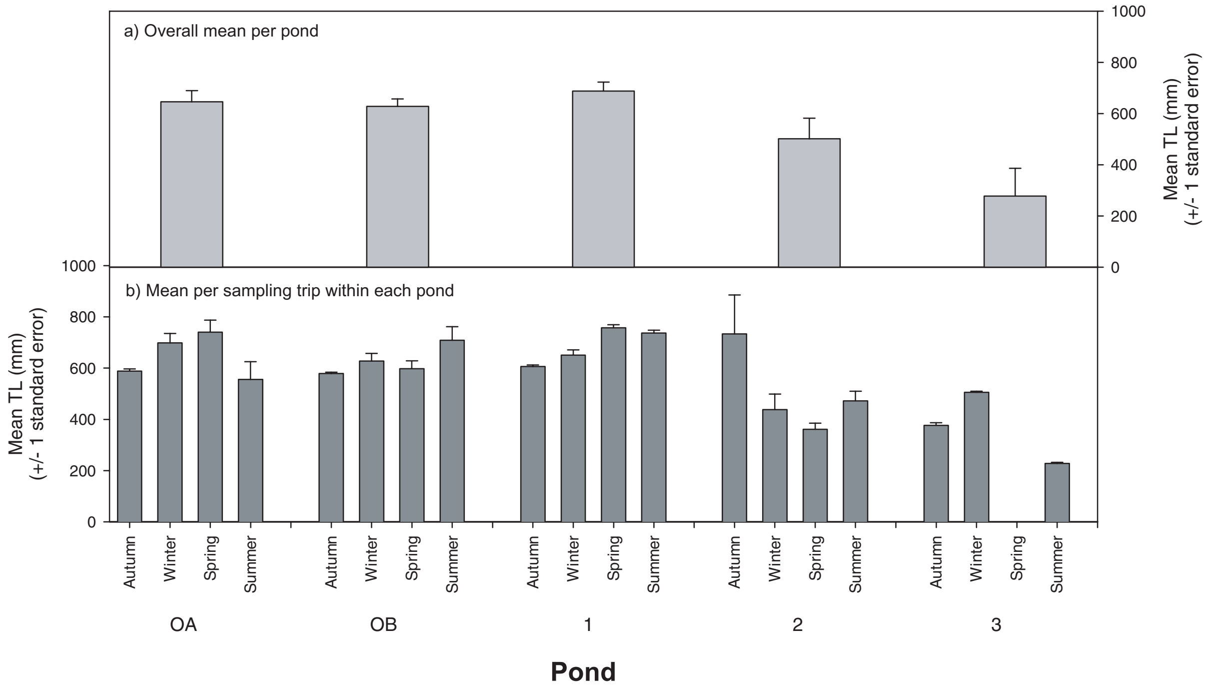


Figure 11. Mean total length (TL) for fishes collected by gill nets within each concentrator pond.

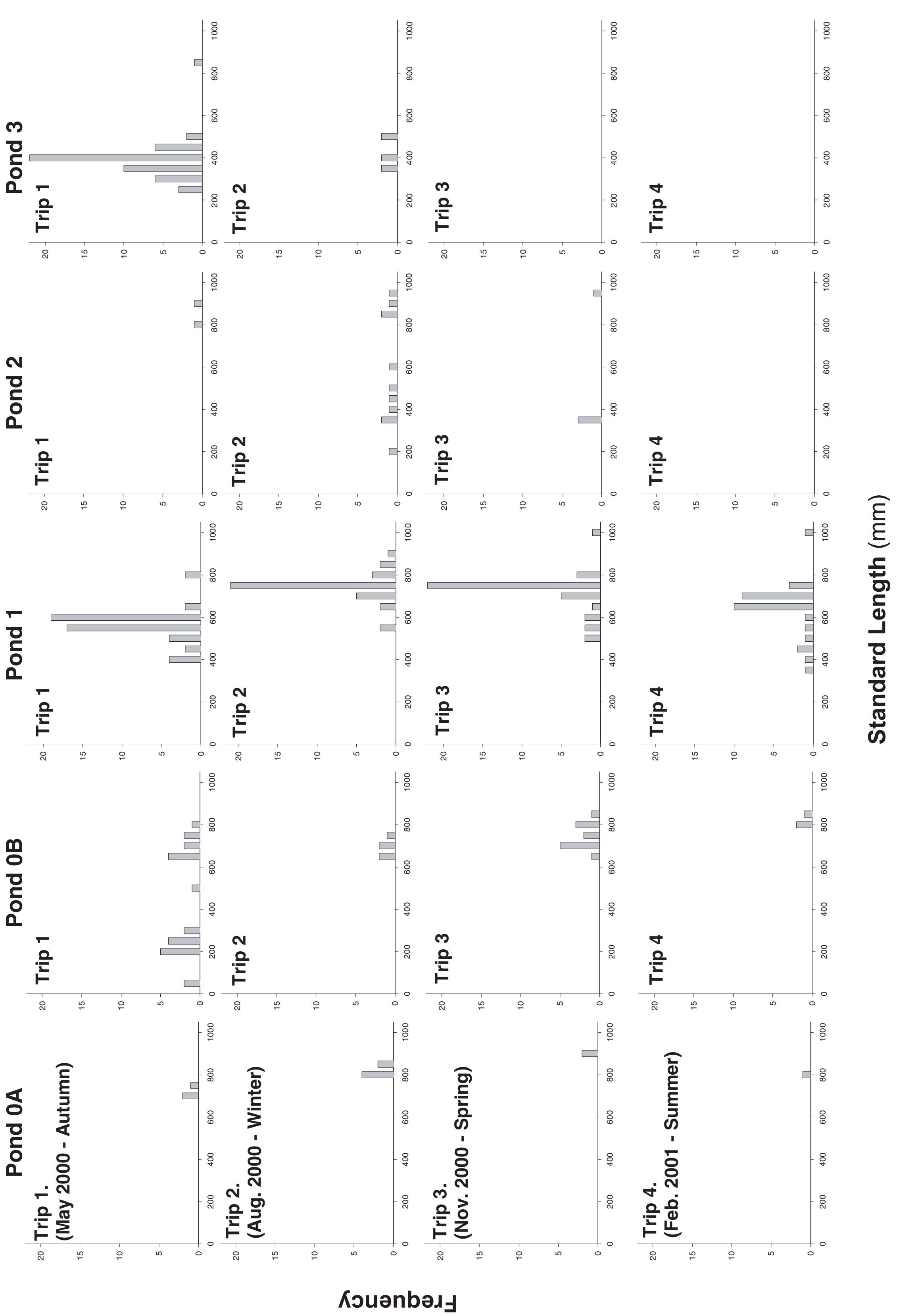


Figure 12. Length-frequency information for *Elops hawaiiensis* captured throughout the study.

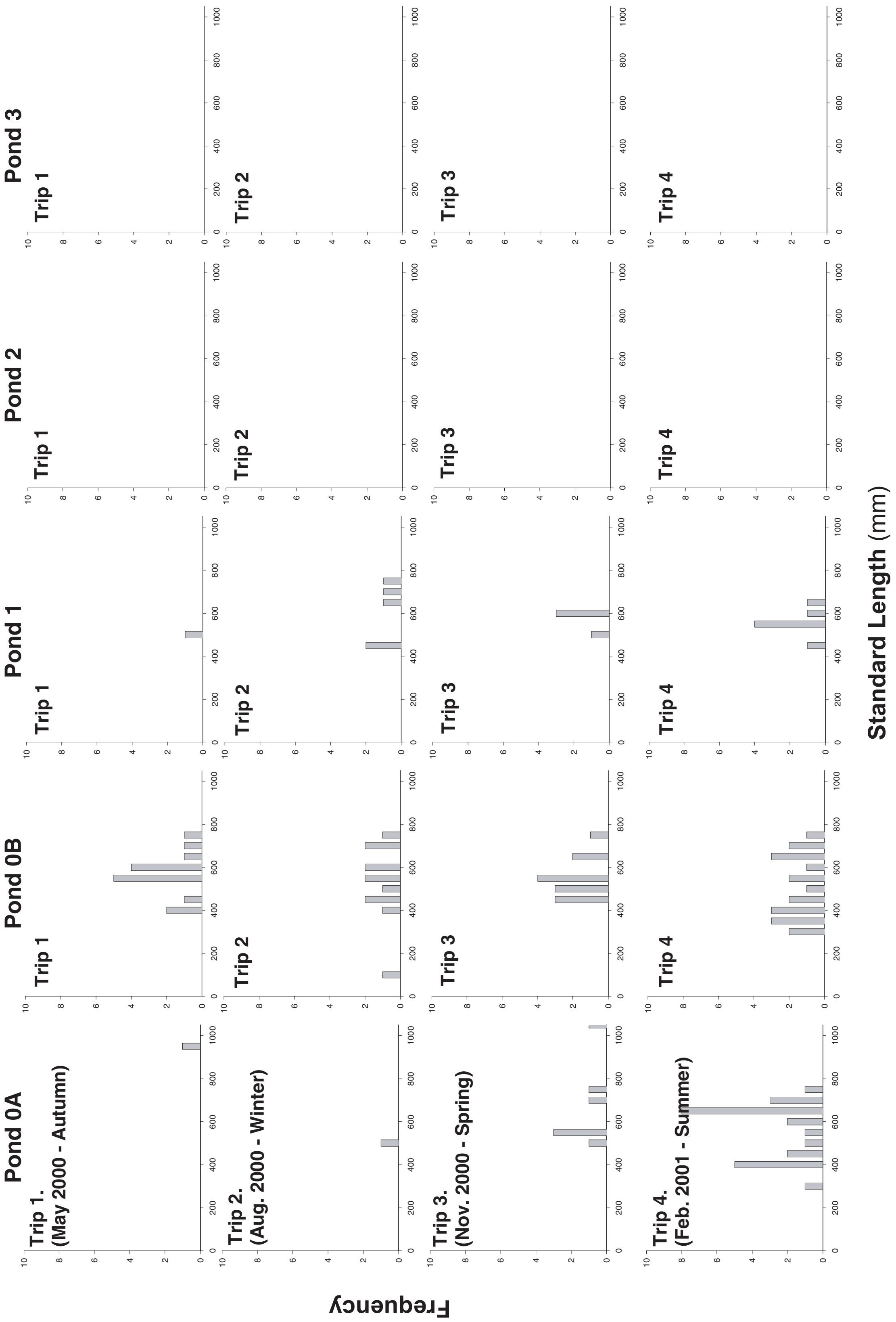


Figure 13. Length-frequency information for *Scomberoides commersonnianus* captured throughout the study.

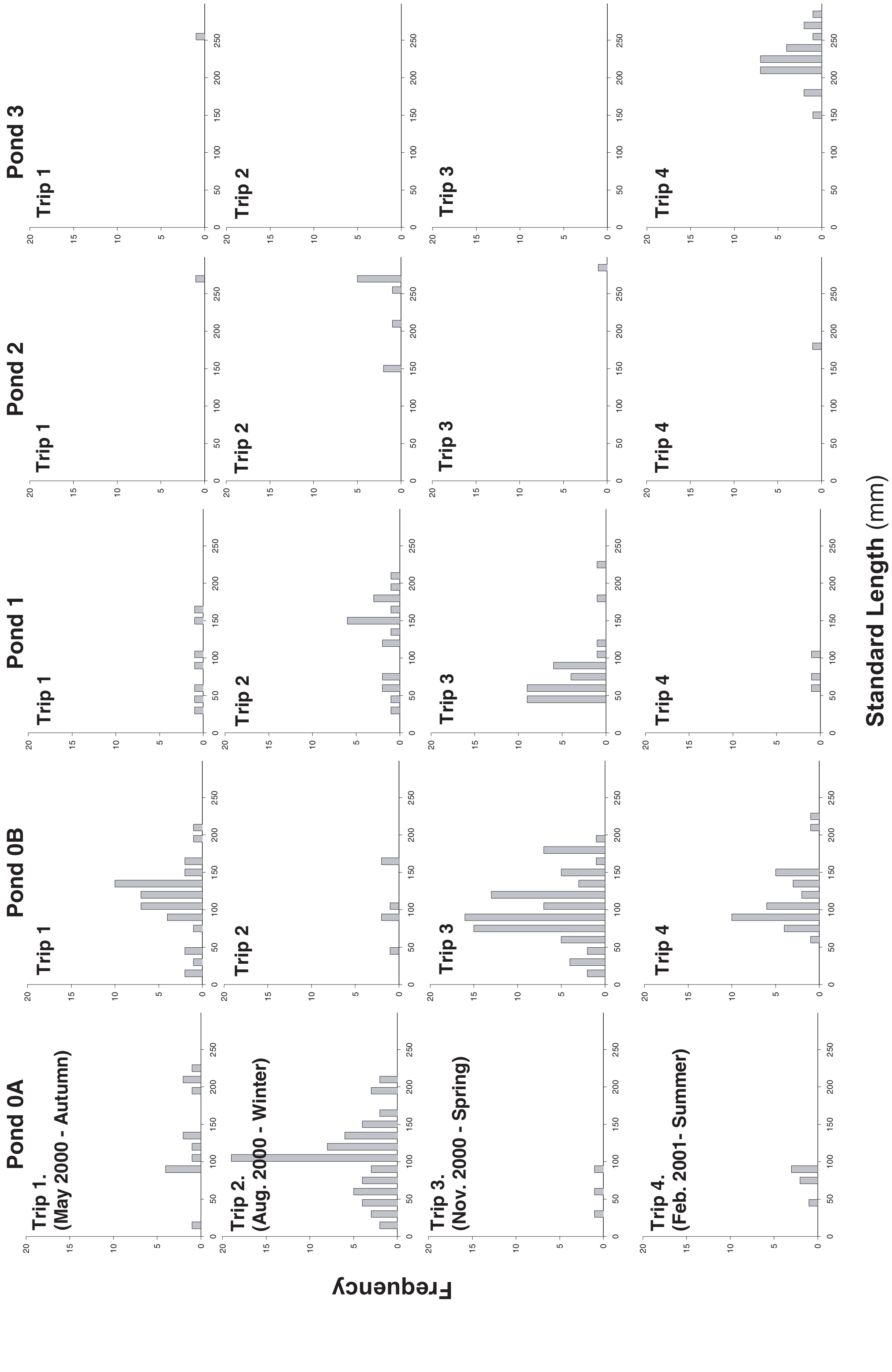


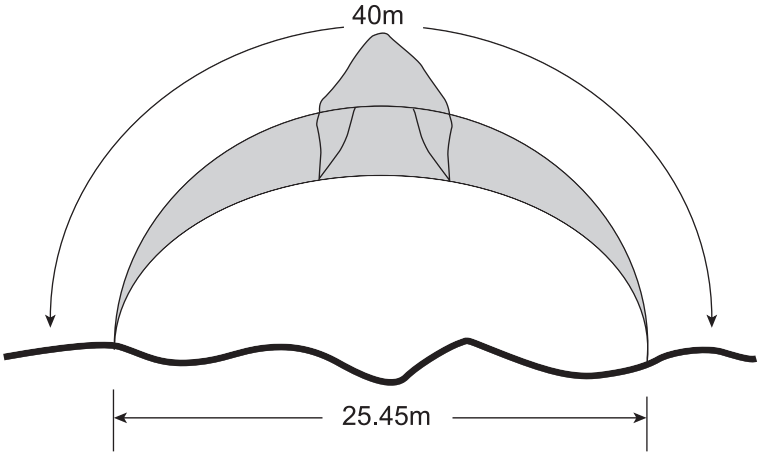
Figure 14. Length-frequency information for *Amniataba caudovittatus* captured throughout the study.

12.0 Appendices

Appendix 1. Fish numbers, biomass and nutrient estimate calculations

Seine Net

The area sampled with a 40m seine can be calculated by assuming the net is set in a perfect half-circle at every shot. That is;



Circumference = $2\pi R$

$$R = \frac{80}{2\pi}$$

R = 12.74 m

∴ The length of bank sampled by each shot is 25.48 m

Area sampled $= \pi R^2$

$= \pi \times 12.74^2$

$= 509.64\ m^2$

∴ The area sampled by the seine net is only half of this at 255 m^2

Estimates of fish biomass are calculated by measuring the perimeter of each pond and by the length of bank each shot covers (i.e. 25.45 m). By using the formula below the fish biomass of the pond can be estimated;

Biomass Estimate = <u>(Mean weight of catch per seine) x (Total pond perimeter bank)</u>
(from Seine) (Bank length covered by each shot).

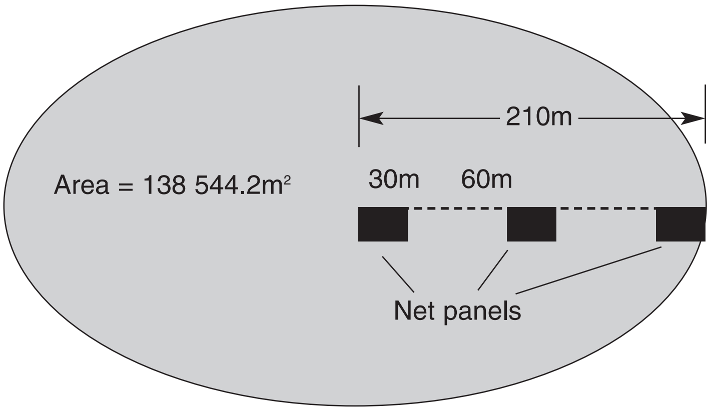
The standard error of the estimate can be calculated in a similar fashion using the error estimate of each shot in place of mean weight of catch per seine.

In a similar way described above fish numbers and their associated errors can also be estimated.

Gill nets

Low Estimate

Each individual net is 30 m long and is set 60 m apart from other nets. The three nets (referred to as a fleet) are assumed to be non-independent and may have a sampling area of a circular shape, the radius of which is the total length of the individual gill nets and the space between them. That is;



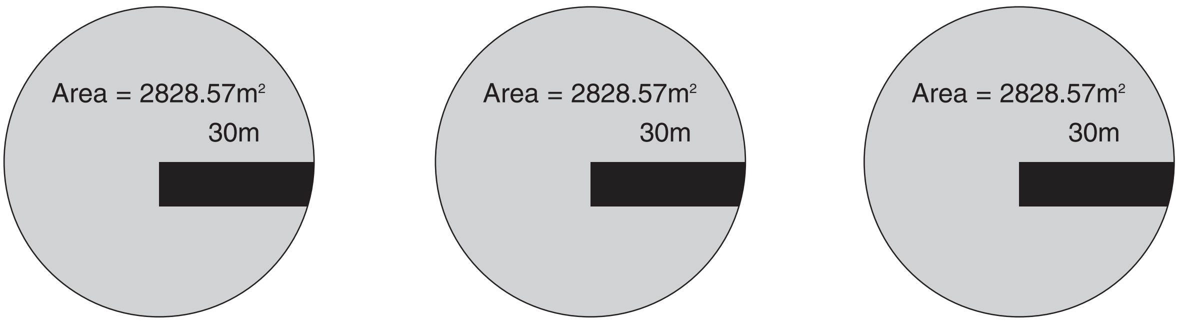
Area sampled $= \pi R^2$

$= \pi x\ 210^2$

$= 138\ 544.2\ m^2$

High Estimates

Each individual net is 30 m long. The three nets are assumed to be independent and have a sampling area of a circular shape, the radius of which is the length of each net. The area sampled is the sum of the area of the three circles. That is;



Area sampled $= 3(\pi R^2)$

$= 3(\pi\ x\ 30^2)$

$= 8\ 485.71 m^2$

Biomass estimates from gill nets are calculated by estimated the total area of each pond (Table 1) multiplying by the mean weight of fish sampled in each pond. This is divided by the either of the area covered by the nets as described above (either 138 544.2 m^2 or 8 485.71 m^2). That is;

The standard error of the estimate can be calculated in a similar fashion using the error estimate of each set in place of mean weight of catch per set.

In a similar way described above fish numbers and their associated errors can also be estimated.

Appendix 2. Alternative methods of quantifying fish abundances.

a). Mark-release-recapture (MRR).

These techniques involve the capture of a relatively large number of fishes from each targeted species, marking each fish, release the fishes and then recapturing on later occasions. By using the ratio of marked to unmarked fish in subsequent samples, an estimate of the number of fishes can be produced.

As with other population estimation techniques, MRR makes several assumptions. The most critical of these is that the subsequent sampling covers the range of areas in which the fish are likely to be dispersed. In the Dampier Salt CPs, fish tagged in CP 0A maybe anywhere within CP 0A, within other CPs or within channels linking some of the CPs. Thus, the application of MRR to estimate population sizes of a range of species would require a large amount of sampling, well beyond the scope of the current project.

b) Echosounders

Echosounders are now common in many fishery situations and are more commonly seen on private recreational vessels. The soundings produced by this equipment can be used to identify species and abundances with "truthing" (i.e. actually capturing and quantifying the species indicated by the echosounder). Typically truthing is achieved by using sounders by using traditional fishing gears (including gill nets) at the same time.

Within the CPs, the use of sounders may be limited due to the shallow nature of the ponds, averaging 0.7 m. However, side sonars may be applied but are likely to have a limited range from the transceiver.

c). Aerial surveys.

Given the shallow nature of the ponds and the relatively high clarity in some ponds, especially at ceratin times of the year, aerial quantification of fish stocks may be possible. Aerial surveys are likely to only quantify large species that are visible from the air. However, the effect of the aircraft on fish behaviour must be examined.

Appendix 3. Detailed estimates of fish numbers, biomass and nutrient levels for each CP and each sampling occasion.

Table A3.1. Estimates of total fish numbers, biomass and nutrient levels in the concentrator ponds of Dampier Salt, May 2000 (Trip 1).

a). Estimates of Fish Numbers

Pond	Net	High Estimate (#) (+/- 1 Standard Error)	Low Estimate (#) (+/- 1 Standard Error)
0A	Seine	64 502.95 ± 32 994.24	
0A	Gill	1 979.80 ± 822.96	121.26 ± 50.41
0A	***Total***	***66 482.75 ± 33 817.20***	***64 624.21 ± 33 044.64***
0B	Seine	281 929.71 ± 31 979.43	
0B	Gill	5 468.02 ± 2 037.81	334.91 ± 121.81
OB	***Total***	***287 397.73 ± 34 017.24***	***282 264.62 ± 32 104.25***
1	Seine	428 965.29 ± 85 962.92	
1	Gill	13 954.83 ± 1 735.00	854.72 ± 106.27
1	***Total***	***442 920.12 ± 87 697.92***	***429 820.01 ± 86 069.19***
2	*Gill (Total)*	*5 378.45*	*329.43*
3	*Gill (Total)*	*57 292.79*	*3 509.13*
All	**Total in System**	**859 471.84 ± 155 532.36**	**780 547.40 ± 151 218.08**

b). Estimates of Fish Biomass

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	4 348.15 ± 2 399.20	
0A	Gill	5 324.72 ± 2 685.74	326.13 ± 164.50
0A	***Total***	***9 672.87 ± 5 084.94***	***4 674.29 ± 2 563.70***
0B	Seine	6 640.67 ± 882.56	
0B	Gill	11 519.14 ± 4 308.53	705.54 ± 263.89
OB	***Total***	***18 159.80 ± 5 191.09***	***7 346.21 ± 1 146.46***
1	Seine	856.21 ± 172.03	
1	Gill	24 045.62 ± 3 037.71	1 472.77 ± 186.06
1	***Total***	***24 901.83 ± 3 209.74***	***2 328.98 ± 358.09***
2	*Gill (Total)*	*19 523.79 1 195.81*	
3	*Gill (Total)*	*32 675.67 2 001.36*	
All	**Total in System**	**104 993.96 ± 13 485.77**	**17 546.64 ± 4 068.25**

c). Estimates of Nutrient Weight due to Fish

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	1 087.04 ± 599.80	
0A	Gill	1 331.18 ± 671.35	81.53 ± 41.13
0A	***Total***	***2 418.22 ± 1 271.24***	***1 168.57 ± 640.93***
0B	Seine	1 660.17 ± 220.64	
0B	Gill	2 879.78 ± 1 077.13	176.38 ± 65.97
OB	***Total***	***4 539.95 ± 1 297.77***	***1 836.55 ± 286.61***
1	Seine	214.05 ± 43.01	
1	Gill	6 011.41 ± 759.43	368.19 ± 46.52
1	***Total***	***6 225.48 ± 802.44***	***582.25 ± 89.52***
2	*Gill (Total)*	*4 880.95*	*298.95*
3	*Gill (Total)*	*8 168.92*	*500.34*
All	**Total in System**	**26 233.49 ± 3 371.44**	**4 386.66 ± 1 017.06**

Table A3.2. Estimates of total fish numbers, biomass and nutrient levels in the concentrator ponds of Dampier Salt, August 2000 (Trip 2).

a). Estimates of Fish Numbers

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	152 298.6 ± 54 285.56	
0A	Gill	1 602.51 ± 244.52	98.15 ± 14.98
0A	***Total***	***153 901.11 ± 54 530.08***	***152 396.80 ± 54 300.54***
0B	Seine	39 038.10 ± 97 842.04	
0B	Gill	2 885.75 ± 772.00	176.75 ± 47.28
OB	***Total***	***241 923.85 ± 98 614.04***	***239 214.85 ± 97 889.33***
1	Seine	121 320.20 ± 57 982.49	
1	Gill	17 563.89 ± 1 384.93	1 075.77 ± 84.83
1	***Total***	***138 884.09 ± 59 367.41***	***122 396.97 ± 58 067.31***
2	*Gill (Total)*	*8 964.09 ± 5 452.64*	*549.04 ± 333.97*
3	*Gill (Total)*	*626.15 ± 626.15*	*38.35 ± 38.35*
All	**Total in System**	**544 299.40 ± 218 590.30**	**514 595.00 ± 210 629.50**
	Trip 1	***859 471.84 ± 155 532.36***	***780 547.40 ± 151 218.06***

b). Estimates of Fish Biomass

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	1 311.60 ± 517.56	
0A	Gill	5 807.43 ± 71.21	355.70 ± 4.36
0A	***Total***	***7 119.03 ± 521.92***	***1 667.30 ± 521.92***
0B	Seine	1 844.27 ± 529.85	
0B	Gill	5 923.23 ± 55.89	362.79 ± 3.42
OB	***Total***	***7 767.50 ± 585.74***	***2 207.06 ± 533.27***
1	Seine	1 224.17 ± 683.50	
1	Gill	38 496.57 ± 131.94	2 357.88 ± 8.08
1	***Total***	***39 720.74 ± 815.45***	***3 582.05 ± 691.59***
2	*Gill (Total)*	*11 227.52 ± 3 240.77*	*687.68 ± 198.49*
3	*Gill (Total)*	*719.45 ± 719.45*	*44.07 ± 44.07*
All	**Total in System**	**66 554.23 ± 5 950.31**	**8 188.15 ± 1 989.34**
	Trip 1	***104 993.96 ± 13 485.77***	***17 546.64 ± 4 068.25***

c). Estimates of Nutrient Weight due to Fish

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	327.90 ± 129.39	
0A	Gill	1 451.86 ± 17.80	88.92 ± 1.09
0A	***Total***	***1 779.76 ± 147.19***	***416.82 ± 130.48***
0B	Seine	461.07 ± 132.46	
0B	Gill	1 480.81 ± 13.97	90.70 ± 0.86
OB	***Total***	***1 941.87 ± 146.43***	***551.76 ± 133.32***
1	Seine	306.04 ± 170.88	
1	Gill	9 624.14 ± 32.99	589.47 ± 2.02
1	***Total***	***9 930.18 ± 203.86***	***895.51 ± 172.90***
2	*Gill (Total)*	*2 806.88 ± 810.19*	*171.92 ± 49.62*
3	*Gill (Total)*	*179.86 ± 179.90*	*11.01 ± 11.02*
All	**Total in System**	**16 638.56 ± 1 487.58**	**2 047.04 ± 497.34**
	Trip 1	***26 233.49 ± 3 371.44***	***4 386.66 ± 1 017.06***

Table A3.3. Estimates of total fish numbers, biomass and nutrient levels in the concentrator ponds of Dampier Salt, November 2000 (Trip 3).

a). Estimates of Fish Numbers

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	160 630.3 ± 84 226.33	
0A	Gill	1 791.44 ± 643.15	109.72 ± 39.39
0A	***Total***	***162 421.70 ± 84 869.84***	***160 740.00 ± 84 265.72***
0B	Seine	332 221.6 ± 83 929.27	
0B	Gill	5 468.02 ± 993.81	334.91 ± 60.87
OB	***Total***	***337 689.60 ± 84 923.09***	***332 556.50 ± 83 990.14***
1	Seine	95 515.32 ± 25 049.71	
1	Gill	13 714.23 ± 1 613.95	839.98 ± 98.85
1	***Total***	***109 229.60 ± 26 663.65***	***96 355.31 ± 25 148.56***
2	*Gill (Total)*	*5 378.45 ± 5 378.45*	*329.43 ± 329.43*
3	*Gill (Total)*	*0*	*0*
All	**Total in System**	**614 719.30 ± 196 456.20**	**589 981.20 ± 193 404.40**
	Trip 1	***859 471.84 ± 155 532.36***	***780 547.40 ± 151 218.06***
	Trip 2	***544 299.40 ± 218 590.30***	***514 595.00 ± 210 629.50***

b). Estimates of Fish Biomass

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	779.41 ± 235.28	
0A	Gill 7 551.52 ± 3 003.07	462.52 ± 183.94	
0A	***Total***	***8 330.93 ± 3 238.36***	***1 241.93 ± 419.22***
0B	Seine	3 978.31 ± 1 845.82	
0B	Gill	14 435.56 ± 2 337.58	884.17 ± 143.17
OB	***Total***	***18 413.87 ± 4 183.39***	***4 862.48 ± 1 988.99***
1	Seine	2 868.57 ± 1 717.49	
1	Gill	36 335.50 ± 5 673.36	2 225.52 ± 347.49
1	***Total***	***39 204.06 ± 7 390.85***	***5 094.08 ± 2 064.97***
2	*Gill (Total)*	*107.57 ± 107.57*	*6.59 ± 6.59*
3	*Gill (Total)*	*0*	*0*
All	**Total in System**	**66 056.44 ± 14 812.60**	**11 205.08 ± 4 473.18**
	Trip 1	***104 993.96 ± 13 485.77***	***17 546.64 ± 4 068.25***
	Trip 2	***66 554.23 ± 5 950.31***	***8 188.15 ± 1 989.34***

c). Estimates of Nutrient Weight due to Fish

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	194.85 ± 58.82	
0A	Gill	1 887.88 ± 750.77	115.63 ± 45.98
0A	***Total***	***2 082.73± 809.59***	***310.48 ± 104.81***
0B	Seine	994.58 ± 461.45	
0B	Gill	3 608.89 ± 584.39	221.04 ± 35.79
OB	***Total***	***4 603.47 ± 1 045.85***	***1 215.62 ± 497.25***
1	Seine	717.14 ± 429.37	
1	Gill	9 083.88 ± 1 418.34	556.37 ± 86.87
1	***Total***	***9 801.02 ± 1 847.71***	***1 273.52 ± 516.24***
2	*Gill (Total)*	*26.89 ± 26.89*	*1.65 ± 1.65*
3	*Gill (Total)*	*0*	*0*
All	**Total in System**	**16 514.11 ± 3 703.15**	**2 801.27 ± 1 118.30**
	Trip 1	***26 233.49 ± 3 371.44***	***4 386.66 ± 1 017.06***
	Trip 2	***16 638.56 ± 1 487.58***	***2 047.04 ± 497.34***

Table A3.4. Estimates of total fish numbers, biomass and nutrient levels in the concentrator ponds of Dampier Salt, February 2001 (Trip 4).

a). Estimates of Fish Numbers

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	174 892.0 ± 53 644.01	
0A	Gill	2 474.74 ± 687.83	151.58 ± 42.13
0A	***Total***	***177 366.70 ± 54 331.84***	***175 043.50 ± 53 686.14***
0B	Seine	376 651.40± 82 250.69	
0B	Gill	4 861.07 ± 658.90	297.74 ± 40.36
OB	***Total***	***381 512.50 ± 82 909.59***	***376 949.20 ± 82 291.04***
1	Seine	189 131.50 ± 84 339.49	
1	Gill	15 217.89 ± 891.43	932.08 ± 54.60
1	***Total***	***204 349.40 ± 85 230.91***	***190 063.60 ± 84 3940.09***
2	*Gill (Total)*	*11 429.21 ± 5 193.17*	*700.03 ± 318.08*
3	*Gill (Total)*	*20 662.97 ± 13 321.25*	*1 265.59 ± 815.91*
All	**Total in System**	**795 320.80 ± 240 986.70**	**744 022.00 ± 221 505.30**
May	**Trip 1**	***859 471.84 ± 155 532.36***	***780 547.40 ± 151 218.06***
Aug	**Trip 2**	***544 299.40 ± 218 590.30***	***514 595.00 ± 210 629.50***
Nov	**Trip 3**	***614 719.30 ± 196 456.20***	***589 981.20 ± 193 404.40***
Feb	**Trip 4**	***795 320.80 ± 240 986.70***	***744 022.00 ± 221 505.30***

b). Estimates of Fish Biomass

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	2 068.81 ± 789.60	
0A	Gill	7 426.68 ± 1 291.40	761.55 ± 159.05
0A	***Total***	***9 495.49 ± 2 080.00***	***2 523.69 ± 868.65***
0B	Seine	3 930.28 ± 1 004.76	
0B	Gill	12 433.72 ± 2 596.84	761.55 ± 159.05
OB	***Total***	***16 364.00 ± 3 601.60***	***4 691.83 ± 1 163.81***
1	Seine	1 785.70 ± 412.32	
1	Gill	35 392.83 ± 3 998.78	2 167.78 ± 244.92
1	***Total***	***37 178.52 ± 4 411.10***	***3 953.48 ± 657.24***
2	*Gill (Total)*	*3 614.99 ± 2 545.35*	*221.42 ± 155.90*
3	*Gill (Total)*	*793.88 ± 452.56*	*48.62 ± 27.72*
All	**Total in System**	**67 446.89 ± 13 091.60**	**11 439.04 ± 2 873.68**
May	**Trip 1**	***104 993.96 ± 13 485.77***	***17 546.64 ± 4 068.25***
Aug	**Trip 2**	***66 554.23 ± 5 950.31***	***8 188.15 ± 1 989.34***
Nov	**Trip 3**	***66 056.44 ± 14 812.60***	***11 205.08 ± 4 473.18***
Feb	**Trip 4**	***67 446.89 ± 13 091.60***	***11 439.04 ± 2 873.68***

c). Estimates of Nutrient Weight due to Fish

Pond	Net	High Estimate (kg) (+/- 1 Standard Error)	Low Estimate (kg) (+/- 1 Standard Error)
0A	Seine	517.20 ± 197.40	
0A	Gill	1 856.67 ± 322.85	190.39 ± 39.76
0A	***Total***	***2 373.87± 520.25***	***630.92 ± 217.17***
0B	Seine	982.56 ± 251.19	
0B	Gill	3 108.43 ± 649.21	190.39 ± 39.76
OB	***Total***	***4 091.00 ± 900.40***	***1 172.96 ± 290.95***
1	Seine	446.42 ± 103.08	
1	Gill	8 848.21 ± 999.70	541.94 ± 61.23
1	***Total***	***9 294.63 ± 1 102.78***	***988.37 ± 164.31***
2	*Gill (Total)*	*903.75 ± 636.34*	*55.35 ± 38.98*
3	*Gill (Total)*	*198.47 ± 113.14*	*12.16 ± 6.93*
All	**Total in System**	**16 861.72 ± 3 272.90**	**2 859.76 ± 718.34**
May	**Trip 1**	***26 233.49 ± 3 371.44***	***4 386.66 ± 1 017.06***
Aug	**Trip 2**	***16 638.56 ± 1 487.58***	***2 047.04 ± 497.34***
Nov	**Trip 3**	***16 514.11 ± 3 703.15***	***2 801.27 ± 1 118.30***
Feb	**Trip 4**	***16 861.72 ± 3 272.90***	***2 859.76 ± 718.34***

Appendix 4. **Results of the quantification of fatty acid methyl esters (FAME) for the *Artemia* sample for Dampier Salt fields. Comparisons with standard sample are also provided. Eicosapentaenoic acid (EPA, 29 R), docosahexaenoic acid (DHA, 42 R) and the sum of highly unsaturated fatty acids (HUFA; Sum (n-3) >or= 20:3(n-3)) are highlighted.**

Code	FA Peak	Dampier Area %	Standard mg/g DW	Code	FA Peak	Dampier Area %	Standard mg/g DW
* 1 R	14:00	1.6	2.5	* 26	20:3(n-3)	0.1	0.1
* 2	14:1(n-5)	1.2	1.8	27	20:4(n-3)	0.4	0.6
3	15:00	0.7	1.2	* 28	22:00	0.3	0.4
4	15:1(n-5)	0.8	1.3	29R	20:5(n-3)	8.6	13.5
* 5R	16:00	14	21.9	* 30	22:1(n-9)	0	0.1
* 6	16:1(n-7)	9.3	14.5	31	22:1(n-7)		
* 7	17:00	0.4	0.7	* 32	23:00		
* 8	17:1(n-7)	0.2	0.3	33	21:5(n-3)	0.1	0.2
* 9R	18:00	3.5	5.5	* 34	23:1(n-9)	0.2	0.3
* 10	18:1(n-9)	20.5	32.1	* 35	22:4(n-6)		
* 11	18:1(n-7)	10.7	16.7	* 36	22:3(n-3)		
* 12	18:2(n-6)-t	0.2	0.3	37	22:5(n-6)		
* 13R	18:2(n-6)-c	9.3	14.6	38	22:4(n-3)		
* 14	19:00	0.1	0.1	* 39	24:00:00		
* 15	18:3(n-6)	0.4	0.6	40	22:5(n-3)	0	0
16	19:1(n-9)	0.3	0.5	* 41	24:1(n-9)		
* 17	18:3(n-3)	9.1	14.2	* 42 R	22:6(n-3)	0.1	0.1
18	18:4(n-3)	1.6	2.5				
* 19	20:00				*Sum (n-3) >or= 20:3(n-3)*	9.3	14.5
* 20	20:1(n-9)	0.4	0.6		*Sum (n-6) >or= 18:2(n-6)-t*	12	18.7
21	20:1(n-7)	0.2	0.3				
* 22R	I.S						
* 23	21:00	0	0.1				
* 24	20:3(n-6)	0.1	0.2				
* 25	20:4(n-6)	1.9	3				

Further analytical information

g wet	0.2572
g dry	0.0373
% DW	14.51
XF 0.5/DW	13.3972
Total mg FAME/g DW	156.7