ABSTRACT

The entrance channel to Lake Illawarra on the southern coast of New South Wales, Australia is home to over 55 species of waterbird. Between 1981 and 2003 four periods of systematic population survey were undertaken by the authors. Herein we analyse this data to examine temporal trends in individual species and foraging guilds. We found that changes in environmental conditions due to engineered habitat reduction appear to have resulted in the decrease of probing and pecking invertebrate feeders (8 species), especially trans-equatorial migrants. Conversely, indigenous invertebrate feeders appear to increase their local populations marginally through the study period. The largest overall change in populations occurred amongst diving fish-eaters, especially Little Pied Cormorant and Australian Pelican, which have increased markedly and both these species now breed locally. The loss of intertidal mud flats and saltmarsh around the southern margins of Windang Bridge appear to be the main cause for the reduction in avian invertebrate-feeder diversity through the study period.

INTRODUCTION

Since the 1950s, the waterbirds that inhabit Lake Illawarra, NSW (Fig. 1), have been studied by various researchers. Harris (1976) and Gibson (1977) provided the first qualitative analyses of available literature and surveys undertaken in the 1950s - 1970s. Those data were supplemented with systematic surveys undertaken from 1981-94 (Wood 1985, Chafer 1989, 1991, Gibson 1989, Chafer & Whelan 1993, Wood & Simcock 1993). Chafer (1997, 2003) and Chafer et al. (1999) continued that research, with additional surveys and interpretation of the ecological relationships of waterbirds with the lakes’ environs. Since 1999, the Illawarra Bird Observers Club has been undertaking regular surveys of the lake entrance to monitor the effects of engineered entrance improvement works. These data are brought together herein to provide an interpretation of temporal water bird distribution and utilisation through the estuary between 1981- 2003.

The phrase waterbird has many interpretations; we define waterbirds as per the Ramsar convention (Delany & Scott 2003), namely “species of birds that are ecologically dependent upon wetlands”. Species included within this analysis are from the orders Podicepiformes (grebes), Pelecaniformes (pelicans and cormorants), Anseriformes (ducks and allies), Ciconiformes (ibis, egrets and allies) and Charadriiformes (shorebirds, gulls and terns). A number of Passerine species (perching birds), Falconiformes (eagles and allies) and Procellariformes (shearwaters and allies) also utilise peripheral aquatic habitats such as reed beds, saltmarsh
and freshwater wetlands. They are not included in this study. Taxonomy follows Christidis & Boles (1994).

In this paper examine temporal patterns in waterbird populations in relation to environmental changes outlined below. Specifically we seek to elucidate if any change waterbird species and/or foraging guilds occurred during the study period, and can any such change be associated with habitat changes that may have occurred as a result of engineered work within the estuary during the study period.

**STUDY AREA AND METHODS**

**Study area**

Lake Illawarra is an estuarine lagoon with a total water area of approximately 3,890 ha, and a catchment of 24,000 ha (Chafer 1997), situated on the south coast of NSW, Australia (Fig. 1). Previous studies have divided the lake into ten compartments based on embayments, aquatic vegetation and faunal distributions (Wood 1989, Chafer 1991, Chafer & Whelan 1992). The estuary to Lake Illawarra encompasses an area of 104 ha, including intertidal sand and mud flats, reedbeds, seagrass meadows, saltmarsh, sheoak swamp and the estuarine channel (Chafer 1997).

**Survey periods**

Data from four periods of systematic survey undertaken by the authors were used in this analysis. During each of these surveys the estuary the 104 ha east of Bevans Island (Fig. 1) was surveyed from multiple land-based observation points mainly during ebb tide when most species are actively feeding through available habitats. Care was taken not to count individuals more than once. Surveys were generally conducted once each month. All surveys were conducted systematically from west to east to cover as much of the entrance habitat as logistically feasible from land. The four survey periods and the number of surveys conducted (in parentheses) were;
- 1982 - 1984 pre southern shore land reclamation (24)
- 1991 - 1993 post southern shore land reclamation (15)
- 1999 - 2000 pre tombolo and training wall construction (24)
- 2001 - 2003 post tombolo and training wall construction (18)

**Foraging guilds**

Foraging guilds are often used in avian ecology to examine how species with similar foraging techniques and prey species partition available habitat for food resources (Baker 1979, Takekawa 2001, Taft et al. 2002). Within the study area there are seven foraging guilds,
- Probing invertebrate carnivore – species with comparatively long bills (>50mm) that probe intertidal sediments to procure invertebrate food items; godwits, curlew, oystercatcher, ibis etc.
- Pecking invertebrate carnivore – species with comparatively short bills (<50mm) that peck the surface and first few cm of intertidal sediments to procure food items; plovers, sandpipers and allies.
- Swimming fish-eaters – species that submerse at least part of their body below the water surface to procure fish in water greater than 100mm depth; cormorants, pelican, grebes.
- Stabbing fish-eaters – species that hunt fish and mobile crustaceans in shallow water less than 300mm
Figure 1. Lake Illawarra estuary 1985 above and 2003 below. Note the land reclamation at the southern end of Windang Bridge and tombolo construction along the southern side of the entrance.
depth and procure food items with a stabbing motion; egrets, herons.

- Diving fish-eaters – species that dive into water to procure fish and mobile crustaceans; terns.
- Grazing herbivores – species that primarily consume seagrasses and associated algae; swan, ducks.
- Omnivores – species that primarily procure food via scavenging; gulls.

Additional to the above foraging guilds, we amalgamated the three fish-eating guilds and the two invertebrate carnivore guilds into two foraging groups (i.e. invertebrate and fish-eaters) to examine if very broad community changes occurred through the study period.

The guild membership, along with common and scientific names of the species and principal habitat used to procure food are summarised in Table 1.

**Environmental change**

During the period considered in this paper (1981-2003), two distinct periods of human-engineered modification of the lake’s estuary have occurred. In the mid 1980s various dredging and land reclamation works were undertaken around the southern margins of Windang Bridge, Picnic Island and Bevans Islands resulting in 7ha of intertidal flat and saltmarsh being reclaimed (Chafer 1997). Then in the 2001 further engineered works on the southern entrance east of Windang Bridge saw the construction of a breakwall and connecting Windang Island to the mainland via a rock tombolo reclaiming some 3 ha of tidal flat (Fig. 1.). We estimate losses in intertidal habitat based on topographic map of the estuary for 1980 (Albion Park 9028-1-N; Central Mapping Authority of NSW 1986), detailed photogrammetric mapping of the estuary in 1993 (Chafer 1997) and SPOT satellite imagery for January 2002, though we note that sandy shoals and seagrass meadow in the estuary vary considerably through time (King et al. 1997, Chafer 1997)

**Statistical analysis**

Changes in waterbird communities in the entrance through time were explored using non-metric multidimensional scaling (MDS) (Clarke & Warwick 1994, Legendre & Legendre 1998) to investigate if a change in the waterbird community has occurred. The 81 surveys were divided into four periods 1982/84, 1991/93, 1999/2000 and 2001/2003. Data in the analysis was restricted to 46 species that were observed on at least three occasions during one of the survey periods (Table 1). Data were 4th root transformed to reduce heteroscedasticity (Zar 1984, Clarke & Warwick 1984). For the MDS, Bray-Curtis dissimilarity coefficient was computed from the species-time matrix using PRIMER 5 software (Plymouth Routines in Multivariate Ecological Research, Primer-E 2000). MDS was permuted 10 times and the median stress value used to describe the efficiency of the resultant 2-dimensional ordination diagram.

The MDS plots produced in Primer-5 allow bubble plots of taxon populations to be superimposed on the location of each count within the two dimensional plot (Clarke & Warwick 1994). This permits visualisation of individual species (or guild) trend through the whole study period and between seasons (Figs 3-11).

Additionally we ran separate MDS on the seven functional foraging guilds and two functional foraging groups
Table 1. Waterbird species found in the Lake Illawarra estuary used in this study, their principal foraging behaviour utilised for the purpose of this research (guild membership) and preferred habitat used within the estuarine environment.

| Common Name      | Scientific Name             | Guild membership | Principal habitat used   |
|------------------|----------------------------|------------------|--------------------------|
| Black Swan       | Cygnus atratus             | H                | seagrass meadow          |
| Pacific Black Duck| Anas superciliosa          | H                | seagrass meadow          |
| Grey Teal        | Anas gracilis              | H                | seagrass meadow          |
| Chestnut Teal    | Anas castanea              | H                | seagrass meadow          |
| Hoary-headed Grebe| Anhinga melanogaster      | SF               | estuarine channel        |
| Little Pied Cormorant| Phalacrocorax melanoleucos| SF               | estuarine channel        |
| Pied Cormorant   | Phalacrocorax varius       | SF               | estuarine channel        |
| Little Black Cormorant| Phalacrocorax sulcirostris| SF               | estuarine channel        |
| Great Cormorant  | Phalacrocorax carbo        | SF               | estuarine channel        |
| Australian Pelican| Pelecanus conspicillatus  | SF               | estuarine channel        |
| White-faced Heron| Egretta novaehollandiae    | STF              | mud flats/seagrass       |
| Little Egret     | Egretta garzetta           | STF              | mud flats/seagrass       |
| Great Egret      | Ardea alba                 | STF              | mud flats/seagrass       |
| Striated Heron  | Butorides striatus         | STF              | mud flats/seagrass       |
| Australian White Ibis | Threskiornis molucca     | PIC              | mud flats/seagrass       |
| Royal Spoonbill  | Platelea regia             | PIC              | intertidal sands and muds|
| Bar-tailed Godwit| Limosa lapponica           | PIC              | intertidal sands and muds|
| Whimbrel         | Numenius phaeopus          | PIC              | intertidal sands and muds|
| Eastern Curlew   | Numenius madagascariensis  | PIC              | intertidal sands and muds|
| Marsh Sandpiper  | Tringa stagnatilis         | SIC              | intertidal sands and muds|
| Common Greenshank| Tringa nebularia           | SIC              | intertidal sands and muds|
| Grey-tailed Tattler| Heteroscelus brevipes     | SIC              | intertidal sands and muds|
| Great Knot       | Calidris temuarostris      | SIC              | intertidal sands          |
| Red Knot         | Calidris canutus           | SIC              | intertidal sands          |
| Sanderling       | Calidris alba              | SIC              | intertidal sands          |
| Red-necked Stint | Calidris ruficollis        | SIC              | intertidal sands          |
| Sharp-tailed Sandpiper| Calidris acuminata       | SIC              | intertidal muds           |
| Curlew Sandpiper | Calidris ferruginea        | SIC              | intertidal muds           |
| Pied Oystercatcher| Haematopus longirostris    | PIC              | intertidal sands and muds|
| Black-winged Stilt| Himantopus himantopus     | SIC              | intertidal muds           |
| Pacific Golden Plover| Pluvialis fulva           | SIC              | intertidal sands          |
| Grey Plover      | Pluvialis squatarola       | SIC              | intertidal sands          |
| Red-capped Plover| Charadrius ruficapillus    | SIC              | intertidal sands          |
| Double-banded Plover| Charadrius bicinctus     | SIC              | intertidal sands          |
| Lesser Sand Plover| Charadrius mongolus       | SIC              | intertidal sands          |
| Greater Sand Plover| Charadrius leschenaultii  | SIC              | intertidal sands          |
| Masked Lapwing   | Vanellus miles             | SIC              | intertidal sands and muds|
| Pacific Gull     | Larus pacificus            | O                | intertidal sands          |
| Kelp Gull        | Larus dominicanus          | O                | intertidal sands          |
| Silver Gull      | Larus novaehollandiae     | O                | intertidal sands          |
| Caspian Tern     | Sterna caspia             | DF               | estuarine channel        |
| Crested Tern     | Sterna bergii             | DF               | estuarine channel        |
| Common Tern      | Sterna hirundo            | DF               | estuarine channel        |
| Little Tern      | Sterna albifrons          | DF               | estuarine channel        |
| Whiskered Tern   | Chlidonias hybridus       | DF               | estuarine channel        |

H = grazing herbivore, O = Omnivore, PIC = probing invertebrate carnivore, SIC = pecking invertebrate carnivore, SF = swimming fish-eater, STF = stabbing fish-eater, DF = diving fish-eater.

Described in the methods. Where species diversity is described we used the Shannon-Weiner index $H'$ (Zar 1984, Legendre & Legendre 1998). Difference between survey periods for fish-eating and invertebrate carnivore groups was analysed using analysis of similarities - ANOSIM (Clarke 1993, Underwood et al. 2003). This analysis compares relative dissimilarities between species population samples (defined a priori), using permutation/randomisation methods on a similarity matrix.
Changes in the waterbird community (Primer-E 2000). We used the Bray-Curtis measure of dissimilarity on the 4th root transformed count data. We separated summer and winter communities based on results from the MDS analysis. The null hypothesis was that there was no difference between seasonal communities between the four survey periods.

RESULTS

General trends

The number of individuals present during the study period ranged from 250 to 2150 birds from 11 to 25 species (Fig. 2). There was a non-significant general increasing trend in the number of birds record between the fours survey periods (Fig 2). Significant differences in bird assemblages between survey periods were apparent (ANOSIM Global $R = 0.4, P<0.001$) and most pair-wise comparisons between survey periods were likewise significant ($P<0.05$), with the exception of the survey periods 1 and 2 which were not significantly different ($R = 0.03, P = 0.30$). This suggests that a significant change in population composition occurred after 1991.

Seasonal, temporal trends

We found a clear dichotomy of species between seasons was found for the waterbird populations (Fig. 3a, stress = 0.17), with the austral summer being interpreted as September to March and the austral winter as April to August (Fig. 3b). Only four of the surveys did not conform to this strict seasonal dichotomy (Fig. 3b). We also found that temporal sequence of surveys was maintained within the MDS plot (Fig. 3b).

Significant differences were also found between seasonal and survey period assemblages for the four study periods (Global $R = 0.66, P<0.001$). All pair-wise comparison showed significant differences between winter and summer community composition ($P<0.006$). All pair-wise comparisons between winter assemblage survey periods were significantly different (at $P<0.005$) except for the first two winter periods, which were not significantly different ($R = 0.14, P = 0.25$). All pair-wise comparisons between summer assemblage survey periods were significantly different (at $P<0.005$), except for the first two summers, which were not significantly different.

Figure 2. Number of individuals (bars) and species (points) for each survey conducted during the four survey periods between 1982 – 2003.
Changes in the waterbird community

**Figure 3.** MDS results for waterbird populations in the Lake Illawarra estuary for four survey periods between 1982 and 2003. Survey periods (right) 1=1982/84, 2=1991/93, 3=1999/2001, 4=2001/03 and survey month (left) (1 = January, 2 = February etc.), MDS stress = 0.17. Arrow indicates time, note also seasonal discrimination of austral summer above arrow (September - March) and austral winter below arrow (April – August).

Different ($R = 0.12$, $P = 0.12$). These results clearly suggested that some temporal change in waterbird assemblages occurred across the twenty-year study period independently of seasonal influences.

**Species trends**

Of the four swimming fish-eaters, Australian Pelican and Little Pied Cormorant show clear increases in their populations through the four survey periods, with the former more numerous in summer and the latter in winter (Fig. 4). Little Black Cormorant is mainly a summer visitor whose population did not vary significantly over the four survey periods, while Great Cormorant showed only a slight preference for summer. The four stabbing fish-eaters indicated no real seasonal trend, however three species; Great Egret, Striated Heron and White-faced Heron show increased frequency in the two latter survey periods, while Little Egret suggested no significant change through the study period (Fig. 5).

Four diving fish-eaters were analysed through the study period. Crested Tern, which breeds locally, showed it is more numerous in summer, though no significant population trend occurred through the study period. Common Tern, which is a summer migrant, also showed no real trend, though they were absent in 1991/93. Caspian Tern is slightly more frequent in winter and was most numerous in 1999/2001. Little Tern, which is migratory and used to breed locally (Gibson 1977, Chafer & Brandis 1991), has declined significantly (Fig. 6).

Of the probing invertebrate eaters, it can be inferred that nomadic Australian White Ibis and Royal Spoonbill were mainly winter visitors and that their populations have increased through the survey period. Conversely the migratory Eastern Curlew and Bar-tailed Godwits are summer visitors and both displayed a reduction in population size over the four survey periods (Fig. 7). Of the pecking invertebrate carnivores (shorebirds), seven species show they are clearly summer visitors and that their individual populations have declined significantly across the survey period, whilst the winter migrant from New Zealand (Double-banded Plover) have become more numerous (Fig. 8). Conversely the three of the four indigenous shorebird species that breed locally (Red-capped Plover, Masked...
Figure 4. MDS results of population scores (bubble size) for swimming fish-eaters through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. All these species are indigenous breeding nomads, with local breeding populations.

Figure 5. MDS results of population scores (bubble size) for stabbing fish-eaters through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. All these species are indigenous breeding nomads, except Striated Heron, which is a breeding resident.
Figure 6. MDS results of population scores (bubble size) for diving fish-eaters through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. Crested Tern is a resident breeder, Little and Common Tern are summer migrants, Caspian Tern nomadic.

Lapwing and Pied Oystercatcher showed no real change in population trend across time, whilst Black-winged Stilt has increased (Fig. 9).

The two most common omnivores, Silver and Kelp Gull, showed little seasonal difference. There was no significant trend in the Kelp Gull population until 2001 after which they became conspicuously absent during summer months. The only notable change for Silver Gull was an increased population in the summer of 2001/02 (Fig. 10).

The grazing herbivores showed a consistent trend through the study period of increasing their use of the estuary especially after 1991/93, with Grey and Chestnut Teal slightly more frequent in winter and Pacific Black Duck and Black Swan slightly more frequent in summer (Fig. 11).

Trends in foraging guilds

We examined if groups with different foraging strategies changed collectively through time. As for the general species trends, the temporal sequence of the surveys periods and summer - winter assemblages was maintained within the 2-dimensional plots (stress = 0.11). The probing invertebrate feeders declined through summer survey periods and marginally increased in winter (Fig. 12). Pecking invertebrate feeders clearly declined through time, notably through summer (Fig. 12). This is a function of the collective population declines of eight migratory shorebird species that predominately foraged in intertidal muds and sands (Figs 7 & 8, Table 1). The small winter increase is due to increases in the population of the Double-banded Plover and Black-winged Stilt (Figs 8 & 9).
Figure 7. MDS results of population scores (bubble size) for probing invertebrate carnivores through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. The ibis and spoonbill are indigenous nomads, while Eastern Curlew and Bar-tailed Godwits are summer trans-equatorial migrants.

It is clear that swimming fish-eaters increased in population size through the study period in both summer and winter (Fig. 13) with Australian Pelican and Little Pied Cormorant accounting for that collective increase (Fig. 4). Stabbing invertebrate feeders show a moderate increase through the 1991/93 survey period (Fig. 13) after which they declined to pre-1991 levels. The diving fish-eaters show little trend through the winter surveys, but clearly has declined in summer (Fig. 13) with Little Tern largely responsible for this trend (Fig. 6).

Grazing ducks and swan have increased their collective populations for both summer and winter since 1991/93 (Fig. 14), while in summer the omnivorous gulls increased in the summers of 1999/2001, apparently declining again in the most recent survey period (Fig. 14).

Trends in functional feeding communities

Overall, the invertebrate carnivores have declined significantly through summer and there was little overall temporal trend through the winter surveys (Fig. 15a, stress =0.09). For the fish-eaters, there was an increase in collective populations through time especially in winter (Fig. 15b). For the winter fish-eating populations the results show that collective population diversity from the first two survey periods was similar and that they were significantly different than population in the latter two surveys. For winter invertebrate carnivores, the result was opposite with latter populations significantly different populations from the first two survey periods (Fig. 16, Table 2). For the summer populations the results show a clear and significant
Figure 8. MDS results of population scores (bubble size) for pecking invertebrate carnivores through time 1982/83 – 2002/03 (arrow). Arrow indicates time, above arrow is austral summer, below arrow is austral winter. All these species are summer palaeartic migrants from Siberia except Double-banded Plover, which is a winter migrant from New Zealand.

Grey-tailed Tattler

Common Greenshank

Curlew Sandpiper

Red Knot

Pacific Golden Plover

Sanderling

Red-necked Stint

Double-banded Plover
Figure 9. MDS results of population scores (bubble size) for pecking invertebrate carnivores through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. All these species are indigenous breeding residents.

Figure 10. MDS results of population scores (bubble size) for omnivores through time 1982/83 – 2002/03. Arrow indicates time, above arrow is austral summer, and below arrow is austral winter. All these species are breeding residents.
Table 2. ANOSIM results for similarities in functional community structure through winter for survey periods between 1982-2003 for the entrance to Lake Illawarra.

| comparison   | winter fish eaters | winter invertebrate eaters |
|--------------|--------------------|---------------------------|
|              | R                  | significance              | R                      | significance |
| w1, w2       | 0.259              | ns                        | 0.169                  | ns          |
| w1, w3       | 0.331              | xx                        | 0.544                  | xx          |
| w1, w4       | 0.321              | xx                        | 0.617                  | xx          |
| w2, w3       | 0.077              | ns                        | 0.088                  | ns          |
| w2, w4       | 0.014              | ns                        | 0.040                  | ns          |
| w3, w4       | 0.061              | ns                        | 0.220                  | ns          |

R is the ANOSIM statistic, ns is not significant, xx is significant at the 1% level, x is significant at the 5% level.

Summary for:
- winter fish eaters w1=w2<=w3=w4,
- winter invertebrate feeders w1=w2=>w3=w4

Table 3. ANOSIM results for similarities in functional community structure through summer for four survey periods between 1982-2003 for the entrance to Lake Illawarra.

| comparison   | summer fish eaters | summer invertebrate eaters |
|--------------|--------------------|---------------------------|
|              | R                  | significance              | R                      | significance |
| s1, s2       | 0.230              | ns                        | 0.152                  | ns          |
| s1, s3       | 0.694              | xx                        | 0.622                  | xx          |
| s1, s4       | 0.623              | xx                        | 0.651                  | xx          |
| s2, s3       | 0.437              | xx                        | 0.332                  | xx          |
| s2, s4       | 0.408              | x                         | 0.248                  | ns          |
| s3, s4       | 0.177              | ns                        | 0.264                  | ns          |

R is the ANOSIM statistic, ns is not significant, xx is significant at the 1% level, x is significant at the 5% level.

Summary for:
- summer fish eaters s1=s2<<s3=s4,
- summer invertebrate feeders s1=s2>>s3=s4
Figure 11. MDS results of population scores (bubble size) for grazing herbivores through time 1982/83 – 2002/03. Arrow reflects population trend through time, above arrow is austral summer, below arrow is austral winter. All species are nomadic breeding visitors.

Figure 12. MDS results for population scores (bubble size) for probing invertebrate carnivores (Guild 1) and pecking invertebrate carnivores (Guild 2). Austral summer populations are above the arrow (indicating time) and austral winter is below. Data are for four survey periods between 1982-2003.

Environmental change

Comparison of the estuaries topography between 1985, 1993 and 2003 provide an estimate of the loss of intertidal substrates (Fig. 18). In 1988/89 approximately 7 ha of intertidal flat and saltmarsh was reclaimed for the development of picnic grounds around the southern end of Windang Bridge. This change altered how tidal exchange into the lake occurred by removing the southern channel (Fig. 1). Additionally, it removed most of the suitable habitat used by Pacific Golden Plover, Grey-tailed Tattler, Sharp-tailed Sandpiper, Curlew Sandpiper and Great Knot. In 2000/01 a further 3 ha of intertidal flat was lost to the.
**Figure 13.** MDS results for population scores (bubble size) for swimming fish-eaters (Guild 3), stabbing fish-eaters (Guild 4) and diving fish eaters (Guild 5). Austral summer populations are above the arrow (indicating time) and austral winter is below. Data are for four survey periods between 1982-2003.

**Figure 14.** MDS results for population scores (bubble size) for herbivores (Guild 6), and omnivores (Guild 7). Austral summer populations are above the arrow (indicating time) and austral winter is below. Data are for four survey periods between 1982-2003.
Changes in the waterbird community

**Figure 15.** MDS results for population scores (bubble size) for all invertebrate-eaters and all fish-eaters. Austral summer populations are above the arrow (indicating time) and austral winter is below. Data are for four survey periods between 1982-2003.

**Figure 16.** Differences in species diversity \( H' \) amongst the winter fish eating and invertebrate eating communities between the four survey periods. Error bars are 95% confidence intervals.

**Figure 17.** Differences in species diversity \( H' \) amongst the winter fish eating and invertebrate eating communities between the four survey periods. Error bars are 95% confidence intervals.

dischussion

Since the first engineered changes in the lake estuary were undertaken in the late 1980s six species have declined dramatically from that environment; Pacific Golden Plover, Grey-tailed Tattler, Curlew Sandpiper, Sharp-tailed Sandpiper, Great Knot and Sanderling.
Changes in the preferred intertidal habitat used by these species around the southern Windang Bridge is postulated as the main contributing reason for the demise of these species (Figs 7 & 8) as predicted by Smith & Chafer (1985). In addition, obvious declines in other once numerous species have occurred, in particular Red-necked Stint, Lesser Sand Plover, Bar-tailed Godwit, Common Greenshank, Little Tern, Red Knot and Eastern Curlew (Figs 7 & 8). The apparent increase in sandy intertidal flats within the estuary east of the bridge seems to have favoured Double-banded and Red-capped Plover, with both species’ populations increasing since 1991 (Fig. 8). The increase in seagrass/algae beds around the estuary islands, under the bridge and the northern shoreline east of the bridge (Fig. 18) appear to have favoured increased populations of Grey and Chestnut Teal, Pacific Black Duck, Great Egret, White-faced Heron, Royal Spoonbill, Striated Heron, Little Pied Cormorant and Australian Pelican (Figs 4, 5 & 11). It is assumed that the increase in seagrass/algae beds in combination with an increased tidal exchange has provided additional suitable habitat for smaller sized fish and crustaceans that are favoured food for these latter species, whilst the macrophytes and algae obviously provide increased food resources for the ducks and swan.

There are two other factors that may have influenced population declines in the shorebird species (pecking invertebrate eaters). The first could be due to a possible global decline in the total migratory population visiting Australia and NSW in particular (Delany & Scott 2003, Chafer 2003). This position should be treated with caution as long-term studies in the Shoalhaven estuary (80km south of Windang) show that most of the migratory shorebird species display some measure of temporal periodicity in populations, increasing and decreasing with changes in habitat availability and meso-scale climatic conditions (Chafer 1998 and unpublished data). The second possible factor is increased disturbance from human recreational activities, which are known to influence shorebird behaviour (Kingsford 1990). There is no specific data to test this hypothesis in the study area; however personal observations by the authors through the study period suggest that human disturbance has not increased significantly. The disturbance theory is further countered by the continued increase in Double-banded Plover population and the four indigenous shorebird species (Figs 8, 9) which predominately use the entrance shoals for feeding and roosting, coupled of course with the increased fish-eating species’ populations which also use the entrance shoals for roosting.

Additional to the above observations, is the serious decline in the Little Tern population. The population that frequented Windang during the study period was predominately part of the non-breeding population from south-east Asia (Chafer & Brandis 1991) and was one of the largest populations in NSW (Smith 1990). No obvious causal explanation for this decline can be postulated.

The notable increase of fish-eating species through the study period is consistent with the local increase in breeding populations of these species. Of the four cormorant species, no local breeding was known prior to 1980 (Gibson 1989). Subsequent to 1985, all four species began to breed in the Illawarra, especially at Korrongulla Swamp, and the pelican commenced breeding locally on the Five Islands.
Nature Reserve (Battam et al. 1986, Wood 1988, Chafer 1997). These breeding colonies have persisted through the study period and the Lake Illawarra estuary is a major food resource for these populations.

CONCLUSION

We have shown that patterns in seasonal and temporal use by waterbirds in the Lake Illawarra estuary can be easily illustrated using available data. Analysis of these data suggests that the removal or alteration of preferred habitat within the estuary has altered the waterbird population structure using the estuary, from a predominately invertebrate feeding suite of species to a predominately fish-eating suite of species. Most migratory invertebrate carnivores (sandpipers, plovers etc.) have declined or disappeared entirely from the estuary. Cormorants, pelican and egrets have clearly increased their populations substantially through the study period. The combination of engineered change in the Lake Illawarra estuary leading to a reduction in intertidal habitat with muddy substrate appears to be a principal reason for the reduction in pecking invertebrate carnivores (shorebirds) through the study period. At the same time an increase in sandy substrates has seemingly benefited two species of plover (Red-capped and Double-banded). Conversely we found that a supposed improved tidal exchange through the entrance channel and increasing microphyte beds has favoured an increase in fish-eating species and herbivorous grazers. These observations are consistent with the ecological theory (eg. Baker 1979, Taft et al. 2002), who also demonstrate that changes in waterbird assemblage composition changes in relation to estuarine habitat alteration.

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