

# Consequences of climate-induced salinity increases on zooplankton abundance and diversity in coastal lakes

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**ABSTRACT:** Intermittent saline intrusions are a common feature of many coastal lakes and wetlands. These ecosystems are often important sites of biodiversity, biological productivity, and ecosystem services such as the removal of sediment, nutrients, and contaminants from inflowing rivers. Predicted effects of global climate change, including sea level rise, are likely to intensify saline intrusions into such ecosystems. Analyses of taxonomic diversity and abundance of zooplankton at different salinities in Lake Waihola, South Island, New Zealand, are supported by results of laboratory studies of salinity tolerances of 3 crustacean taxa *Gladioferens pectinatus*, *Boeckella hamata* and *Daphnia carinata* obtained from the lake. The field and laboratory analyses show that severe perturbations of zooplankton community structure and abundance are caused by even minor saline intrusions into Lake Waihola that raise the salinity to >1.2 psu. Our analyses of Lake Waihola, and data from brackish ecosystems around the world, show that even relatively small increases in salinity levels can drive such systems to a state of depleted biodiversity and abundance, altering ecosystem functioning.

**KEY WORDS:** Zooplankton diversity · Zooplankton abundance · Climate change · Community structure · Shallow lake · Salinity · Lake Waihola · Saline intrusion

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## INTRODUCTION

Low-lying lakes, wetlands and lagoons are common features of coastal areas of many parts of the world. Such ecosystems are often connected to the sea and may experience tidal fluctuations in water level as well as intrusions of saline water, resulting in either a temporary or long-term brackish state. Salinity may be seasonally variable and can be influenced by variations in sea level, freshwater recharge (precipitation or hydrological flows), and evaporation. Coastal wetlands are particularly at risk from the predicted effects of global climate change (IPCC 2001a), as the global mean sea level is projected to rise by 0.09 to 0.88 m by 2100 (IPCC 2001b), thereby salinizing brackish and many freshwater coastal aquatic ecosystems. In New Zealand, for example, there are an average of 7.4 lakes, wetlands and lagoons (comprising an average of 260.5 ha) per 100 km of coastline that are likely

to be impacted by salinization as a result of a 1 m rise in sea level.

Salinity affects an aquatic organism's ability to osmoregulate. Attempts to classify biological communities in relation to the salinities in which they are found have led to the definition of salinity thresholds that describe the distributions of taxa and communities along salinity gradients (Remane & Schlieper 1971). For example, the threshold salinity level functionally delimiting freshwater from brackish lake communities has been suggested to occur at 2 psu (Jeppesen et al. 1994). Similarly, the salinity threshold between sub-saline and hyposaline waters has been defined as 3 psu (Hammer 1986). Furthermore, species richness along salinity gradients is generally minimised at salinities between 5 and 7 psu (Remane & Schlieper 1971).

Lake Waihola, South Island, New Zealand, is well suited for studying the effects of salinization, due to global climate change, on coastal lake ecosystems. It is

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a medium sized (surface area = 5.4 km<sup>2</sup>), shallow (mean depth = 1.15 m), tidal (mean tidal range ca. 0.40 m) lake, connected to the sea via a 10 km reach of the Taieri River, ca. 30 km southwest of the city of Dunedin. The lake has a diverse fish community and a high catch per unit effort (CPUE) relative to other New Zealand lakes, though not relative to shallow Danish lakes (Jeppesen et al. 2000). Lake Waihola has a hydraulic residence time of 153 d, based on non-tidal, freshwater inflows (Schallenberg & Burns 2003). During drought conditions, when water levels in the Taieri River are low and when other freshwater inputs are small, intrusions of saline water enter the lake, as occurred in the austral summers 1997/98 and 1998/99. Global climate change is expected to affect New Zealand in ways similar to the El Niño climatic pattern, in which westerly and southerly airflows dominate and the east coast of New Zealand experiences dry (drought) conditions more frequently (Mullan 1996, NZMfE 2001). During dry summers, Lake Waihola often experiences saline intrusions which create strong temporal and spatial salinity gradients within the lake. Results of a calibrated hydrological model of the Taieri catchment, which was run using meteorological inputs based on downscaled global circulation models and 2 global climate change scenarios (NZMfE 2001), indicated that runoff in the Taieri catchment will decrease during summer months under both scenarios (B. Fitzharris unpubl. data). In addition to decreased summer freshwater inputs, Lake Waihola will also be affected by a regional sea level rise of between 5 and 66 cm by the year 2050 (NZMfE 2001).

The salinity of Lake Waihola was much higher at times during the Holocene. For example, the lake was part of an estuary during the mid-holocene highstand (ca. 4000 yr before present; see Beaman et al. 1994), when a layer of articulated shells of the estuarine/marine bivalve *Austrovenus stutchburyi*, ca. 1.15 m below the surface of the lake bed, was originally deposited (M. Schallenberg unpubl. data). These shells have been carbon-dated at 4059 to 4232 yr before present (<sup>14</sup>C calibrated age; 1 sigma interval). *A. stutchburyi* does not inhabit the lake at present, which is now habitat for the freshwater mussel *Hyridella menziesi*. Based on current predictions of the effects of global climate change (IPPC 2001b, NZMfE 2001, B. Fitzharris unpubl. data) it is likely that Lake Waihola will return to estuarine conditions.

The purpose of our study was to determine the effects of saline intrusions on the zooplankton biomass and community structure in

Lake Waihola. A combination of: (1) field survey data, (2) experimental salinity toxicity studies, and (3) a review of relevant literature on the responses of zooplankton communities along salinity gradients were applied to infer the future effects of climate change on the structure and functioning of zooplankton communities in freshwater-to-brackish coastal lakes. We test the hypothesis that the salinization of Lake Waihola results in severe reductions in biodiversity and abundance of zooplankton.

## MATERIALS AND METHODS

Background data on Lake Waihola are available in Schallenberg et al. (2003) and Schallenberg & Burns (2003). Zooplankton were collected from Lake Waihola for ca. 1 yr periods in 1997/98 and 1999/2000. Zooplankton were sampled at ca. 14 d intervals from the entire water column at 3 sites along the longitudinal axis of the lake (Fig. 1), using a 15 cm diameter tube sampler. The collected lake water (10 to 40 l, depending on the density of metazooplankton observed) was passed through a 48 µm-mesh zooplankton net, and zooplankton were preserved in 4% buffered formalin. A minimum of 500 zooplankton from each sample were counted in a Sedgwick-Rafter cell. Zooplankton were identified to species where possible. Where the spe-

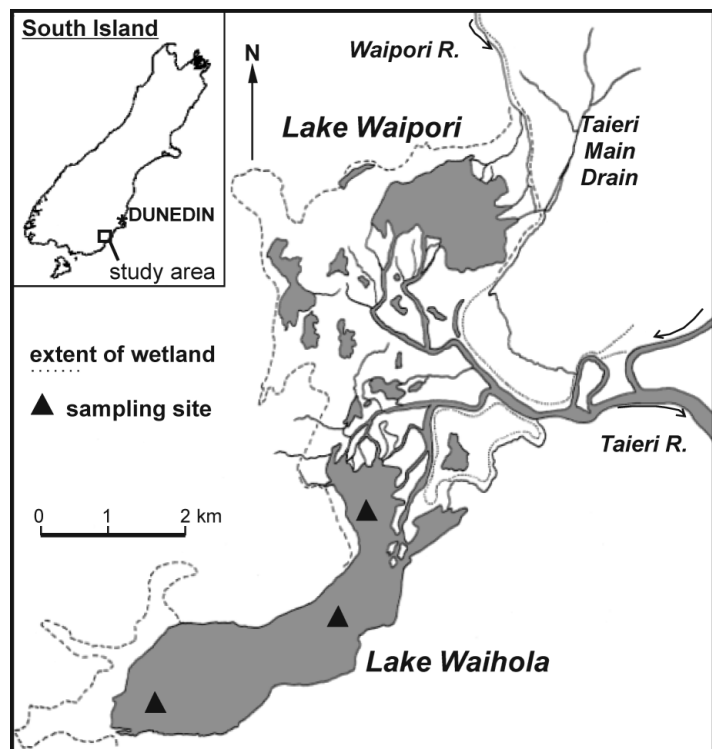


Fig. 1. Location of Lake Waihola, New Zealand, and sampling sites

cies designation of rotifers was uncertain, they were classified to genus and placed in morphospecies categories. Taxonomic guides by Chapman & Lewis (1976), Stemberger (1979) and Streble & Krauter (1988) were used to identify zooplankton taxa. The number of taxa in any 1 sample was termed the taxonomic richness.

Salinity data are stated in practical salinity units (psu). For thalassic (marine-influenced) waters, the ratio of chloride to total dissolved salts is constant, and the coefficient 1.8066 was used to convert chlorinity to salinity, where necessary. Chlorinity and salinity were highly correlated in Lake Waihola ( $R^2 = 0.99$ ,  $p < 0.0001$ ,  $n = 125$ ). Specific conductivity measurements were converted to psu using the OCEANUS 2000 software (Ferreira 2000). Salinity (specific electrical conductivity) was measured in the field using a Hanna model HI 8633 conductivity meter and a YSI (Yellow Springs Instruments) 85 meter unit.

To determine the relationship between salinity and zooplankton community structure, we used abundance-weighted averaging to calculate taxon-specific salinity optima and tolerances (ter Braak 1998). Calculations of salinity optima ( $WA_{opt}$ ) of zooplankton taxa were carried out using the following equation:

$$WA_{opt} = \sum_i^n (A_i \times S_i) / \sum_i^n A_i$$

where  $A_i$  is the taxon's abundance in sample  $i$  and  $S_i$  is the salinity of sample  $i$ , and  $n$  is the number of samples. Taxon-specific 95% salinity tolerance limits ( $WA_{tol}$ ) were calculated based on standard deviations of the weighted average ( $WA_{std}$ ):

$$WA_{tol} = \pm 2 \times WA_{std}$$

$$WA_{std} = \{ \sum_i^n (A_i \times [S_i - WA_{opt}]) / \sum_i^n S_i \}^{0.5}$$

Salinity optima and tolerances were assessed only for those taxa which were present in at least 4 samples. Based on this criterion, 7 taxa were considered itinerant and were excluded from analyses.

We verified the salinity optima and tolerances observed in Lake Waihola field data by assessing the toxicity of salinity to 3 zooplankton taxa using laboratory  $LC_{50}$  methodology. Animals were collected from the lake at least 3 d before experiments began, and acclimated to a defined culture medium (Kilham et al. 1998). They were fed daily 2 mg l<sup>-1</sup> dry wt of the alga *Cryptomonas* sp. and kept under a day/night cycle (16:8 h light:dark) at 10°C. Animals were then exposed to a range of salinity levels representative of the range of salinity measured in Lake Waihola. Salinity was controlled using analytical grade NaCl. Tests were run for a 20 d period. The percentage of animals alive after 96 h in all salinity treatments was used to calculate the salinity at which 50% mortality would have been expected after 96 h (96 h  $LC_{50}$ ).

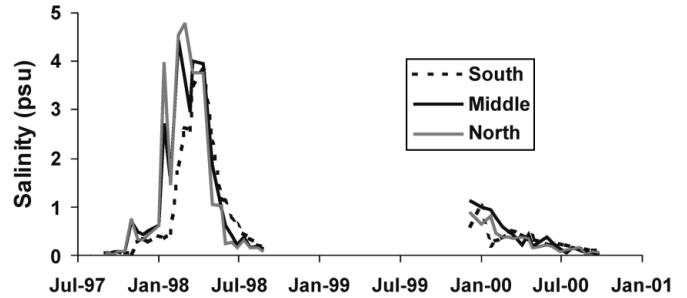


Fig. 2. Salinity at 3 sites (South, Middle, North) in Lake Waihola in 2 non-consecutive years, measured at ca. 14 d intervals

## RESULTS

Climatic conditions differed between the 1997/98 and 1999/2000 sampling periods and, as a result, Lake Waihola experienced a strong saline intrusion in the austral summer of 1998 but not in 2000 (Fig. 2). Consequently, salinity reached 4.7 psu in 1997/98 compared with 1.2 psu in 1999/2000. Although saline intrusions entered the lake via the northern connection to the Taieri River, seawater was generally well mixed throughout the lake by turbulence caused by winds and/or tidal currents, although occasional, brief horizontal spatial gradients were detected (Fig. 2).

The abundance and distribution of zooplankton taxa in Lake Waihola varied with differing salinities in the lake (Fig. 3, Table 1). For example, *Gladioferens pectinatus*, which is considered to be an estuarine copepod (Bayly 1965, Perkins 1974), showed a wide salinity tolerance, whereas *Boeckella hamata* and *Daphnia carinata* were generally restricted to much lower salinities (Fig. 3, Table 1).

The patterns of salinity tolerances of these copepods and *Daphnia* calculated from field data were confirmed by laboratory salinity toxicity tests. The range of salinities to which they were exposed reflected those in the lake, and resulted in the mortality of all animals in less than 11 d at the highest salinities (Fig. 4). The 96 h  $LC_{50}$ s at 10°C were 3.2 psu (1780 ppm Cl<sup>-</sup>) for *Gladioferens pectinatus* (Hall & Burns 2002b), 2.7 psu (1500 ppm Cl<sup>-</sup>) for *Boeckella hamata* (Hall & Burns 2001), and 2.5 psu (1400 ppm Cl<sup>-</sup>) for *D. carinata* (Hall & Burns 2002a).

The zooplankton taxa in Lake Waihola were ranked by their abundance-weighted maximum tolerance to salinity, and coded by general taxonomic groupings to indicate how the general structure of the zooplankton community changed with increasing salinity (Fig. 5). According to the resulting model, cladocerans were effectively absent from the lake at salinities >1.3 psu. Although some rotifer taxa showed low salinity optima and tolerances (e.g. *Keratella cochlearis*, *Pompholyx*

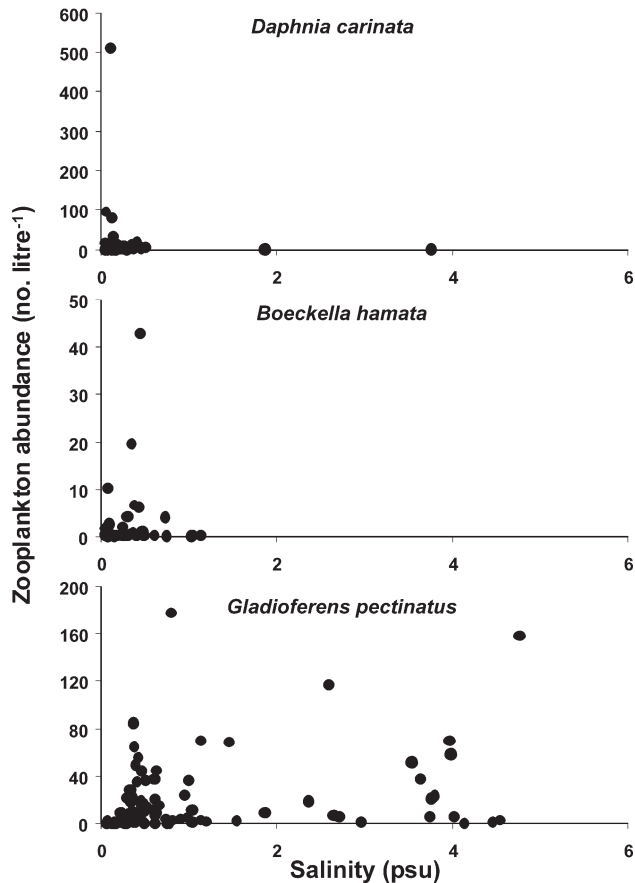


Fig. 3. *Daphnia carinata*, *Boeckella hamata* and *Gladioferens pectinatus*. Abundance (ind. l<sup>-1</sup>) in Lake Waihola, plotted against salinity at the sampling site

*sulcata*), at least some rotifers persisted at all but the highest salinities (e.g. *Hexarthra fennica*). This analysis indicated that as salinity increased in Lake Waihola, the zooplankton community changed from one represented by copepods, rotifers, cladocerans, amphipods and amoebae at low salinities, to one consisting of few species comprising only rotifers and *Gladioferens pectinatus* at salinities above 2.7 psu.

Zooplankton taxonomic richness and abundance in all samples from Lake Waihola, when plotted against salinity at the time of sampling, show that both these indices of zooplankton community structure decrease with even moderate increases in salinity in Lake Waihola (Fig. 6). At the highest salinities recorded, there were never more than 6 taxa present, and zooplankton abundance was below 500 ind. l<sup>-1</sup>, whereas at low salinities, taxonomic richness was generally between 6 and 17 species and abundance ranged from less than 500 to over 5000 ind. l<sup>-1</sup>. The relatively few data at intermediate salinities preclude rigorous modelling of the relationships. However, the upper limit of zoo-

plankton taxonomic richness appeared to decline linearly with increasing salinity (taxonomic richness =  $18 - 2.7 \times \text{salinity}$ ), whereas the upper limit of zooplankton abundance appeared to decline exponentially with increasing salinity {abundance =  $(10 \times [\text{salinity}]^{-1} + 4) \times 100$ }.

## DISCUSSION

If our results from Lake Waihola can be generalized to other coastal freshwater-to-brackish lakes and lagoons, then climate change will have negative impacts on zooplankton communities in such systems. Our data set spans 2 yr in which climatic conditions resulted in different salinity impacts on the lake. In 1997/98, the influence of a strong El Niño climatic pattern and a strong saline intrusion created conditions which are likely to be more common in the future due to climate change (IPCC 2001a,b, NZMfE 2001). The lack of similar conditions in 1999/2000 decoupled the effect of the summer saline intrusion from other sea-

Table 1. Abundance-weighted salinity optima and upper and lower tolerance limits for taxa found in Lake Waihola, New Zealand. Values are in psu and are ranked in descending order of optima

Taxon	Optimum	Lower limit	Upper limit
<i>Gladioferens pectinatus</i>	1.6	0.0	4.7
<i>Hexarthra fennica</i>	1.2	0.0	3.0
<i>Lecane</i> sp.	0.9	0.0	2.3
<i>Notholca</i> sp.	0.9	0.0	3.6
<i>Testudinella</i> sp.	0.8	0.0	1.8
<i>Simocephalus</i> sp.	0.7	0.2	1.2
Cyclopoid copepods	0.7	0.0	2.3
<i>Colurella</i> sp.	0.6	0.0	2.0
<i>Trichocerca</i> sp.	0.6	0.0	1.1
<i>Alona</i> sp.	0.5	0.2	0.8
<i>Paracalliope fluviatilis</i>	0.5	0.0	2.5
Testate amoebae	0.5	0.0	1.9
<i>Polyarthra</i> sp.	0.4	0.0	2.5
<i>Keratella quadrata</i>	0.4	0.0	1.0
<i>Synchaeta</i> sp.	0.3	0.0	2.1
<i>Boeckella hamata</i>	0.3	0.0	0.7
<i>Notommata</i> sp.	0.3	0.0	1.0
<i>Keratella ?testudo</i>	0.3	0.1	0.5
<i>Filinia</i> sp.	0.3	0.0	0.7
<i>Asplanchna</i> sp.	0.3	0.0	1.0
<i>Brachionus</i> sp.	0.3	0.0	0.8
<i>Ceriodaphnia dubia</i>	0.2	0.0	0.7
<i>Pompholyx sulcata</i>	0.2	0.0	0.7
<i>Lophocharis salvina</i>	0.2	0.0	0.8
<i>Ascomorpha</i> sp.	0.2	0.0	0.6
<i>Bosmina meridionalis</i>	0.2	0.0	0.6
<i>Daphnia carinata</i>	0.1	0.0	0.3
<i>Keratella cochlearis</i>	0.1	0.0	0.4

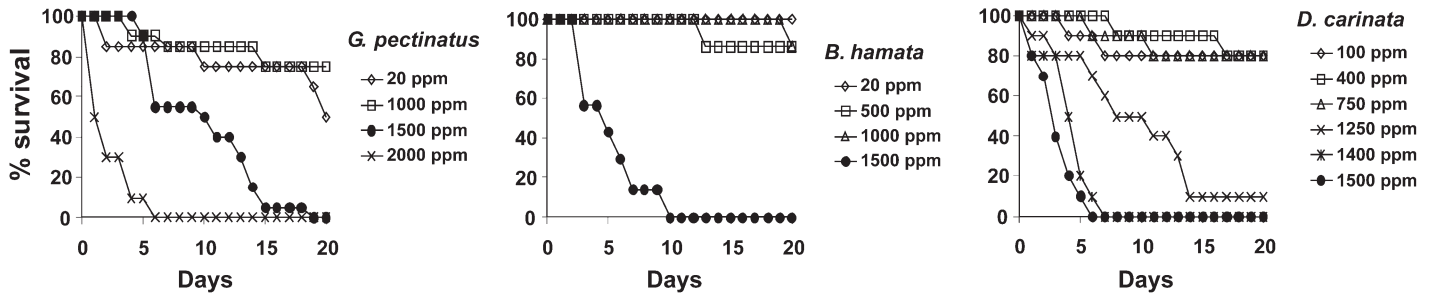


Fig. 4. *Gladioferens pectinatus*, *Boeckella hamata* and *Daphnia carinata*. Percent survival in Lake Waiholo, exposed to different salinities (expressed as chloride concentration) at 10°C over 20 d. Data redrawn from Hall & Burns (2001, 2002a,b)

sonal patterns of water quality and zooplankton community structure in the lake.

A canonical correspondence analysis carried out on the 1997/98 zooplankton data showed that salinity was by far the most important water quality variable structuring the zooplankton community in Lake Waiholo—more important than either nutrients or wind-induced turbidity (Schallenberg & Burns 2003). Salinity alone explained 40% of the species-environment correlation and drove the primary canonical axis of the canonical correspondence analysis. Therefore, the relative importance of salinity in explaining the zooplankton community structure in this study is confirmed in Fig. 7, which shows that the calculated abundance-weighted salinity optima for the taxa in the present study are highly correlated to the primary axis taxa scores from the canonical correspondence analysis. The similarly dominant influence of salinity (relative to other water-quality variables) on zooplankton community structure has also been confirmed in multivariate analyses of zooplankton communities in Brazilian coastal lakes (Attayde & Bozelli 1998) and in lakes of northwestern Canada (Swadling et al. 2000).

As salinity can influence other water-quality variables (e.g. the flocculation of dissolved organic carbon and inorganic matter; Postma 1967, Sholkovitz 1976), saline inputs should influence other aspects of water chemistry in Lake Waiholo. We did not statistically remove the effect of any water chemistry covariates from our analysis of salinity effects, because saline intrusions resulting from climate change will also affect water chemistry. Similarly, we did not isolate the direct effect of salinity from any potential

indirect effects on zooplankton (e.g. via interactions of salinity on inter-specific competition, predation, algal community structure, etc.). Clearly, food web interactions are also likely to affect zooplankton community structure in Lake Waiholo and other similar lakes (Aaser et al. 1995, Jeppesen et al. 2000), and biological interactions affecting zooplankton, such as predation, can interact with salinity variations as has been demonstrated elsewhere (Jeppesen et al. 1994, 1998). The fact that the patterns of salinity optima and tolerances of the 3 key zooplankton taxa in the lake survey data were confirmed by laboratory salinity toxicity tests indicates that variable salinity tolerances were probably a major factor driving the patterns in zooplankton community structure that we observed in Lake Waiholo.

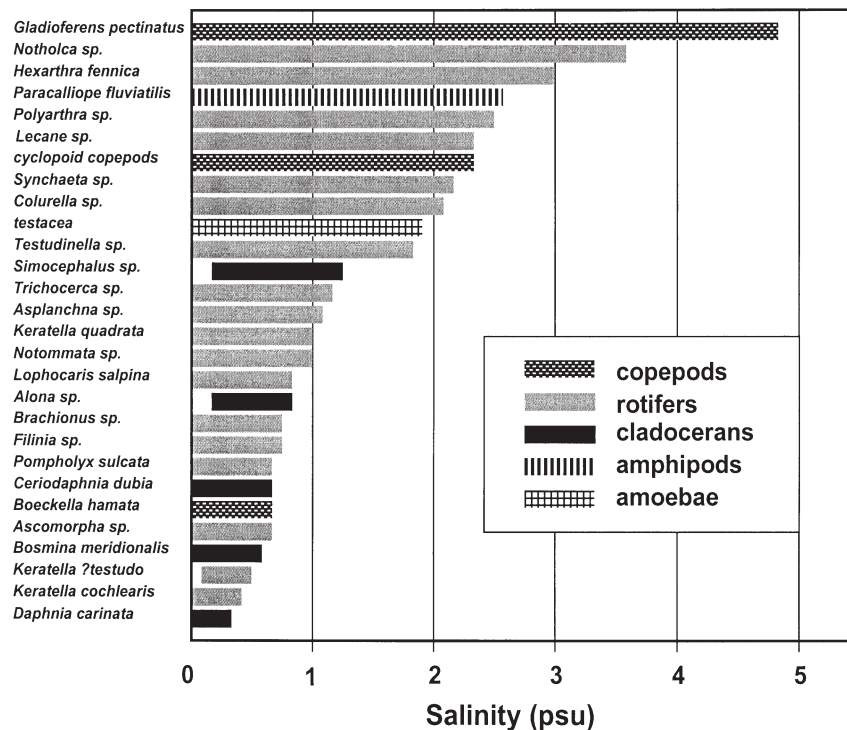


Fig. 5. Salinity tolerances of 28 zooplankton taxa ( $\pm 2$  SD of abundance-weighted salinity optima) in Lake Waiholo. Bar patterns identify broad taxonomic groupings



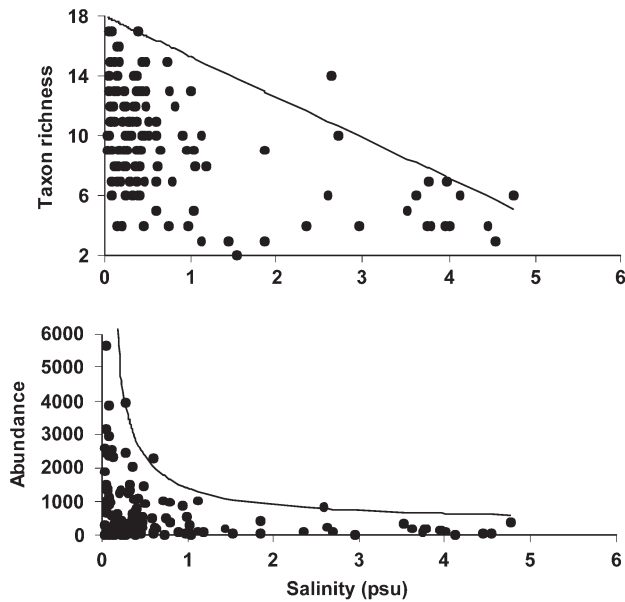


Fig. 6. Zooplankton taxonomic richness (upper panel) and abundance (no.  $l^{-1}$ , lower panel) in relation to salinity of Lake Waihola at the time of sampling. The estimated upper limits of richness and abundance (refer to text) are shown by the lines

Our analysis of abundance-weighted salinity tolerances provides a means of modelling the decline in taxonomic richness as a function of salinity (Fig. 5). This modelled decline fits the observed pattern of taxonomic richness only generally (Fig. 8) and there are 2 striking differences between the 2 patterns. The modelled pattern represents the *potential* taxonomic richness based on abundance-weighted salinity tolerances. At low salinities, the potential richness is not achieved, probably as a result either of biological interactions (e.g. competition, predation) or variation in other environmental factors that limit the distribu-

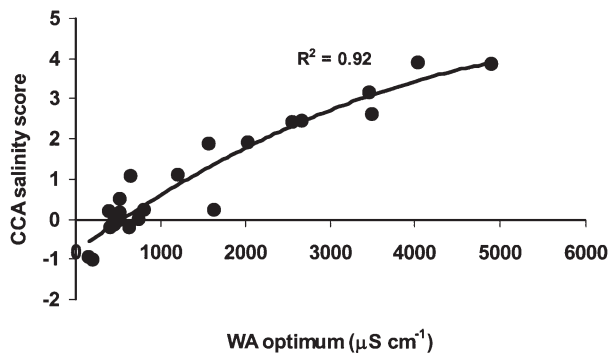


Fig. 7. Correlation of the scores of taxa along the primary axis of a canonical correspondence analysis (CCA) with their abundance-weighted salinity optima (WA). Specific conductivity is used as an index of salinity. The line is the 2nd-order polynomial regression fitted to the data

tion of individual taxa at any one time. The modelled distribution underestimates the species richness at high salinities in Lake Waihola because zooplankton densities were generally very low at a high salinity (Fig. 6). As the model is based on abundance-weighted distributions, the tails of the taxon distributions are truncated where densities are very low and distributions are skewed. Hence, the 2 approaches to modelling the distribution of taxa along the salinity gradient are complementary, but neither provides a complete picture of changes in community structure.

The observed and modelled declines in zooplankton community structure with salinity in Lake Waihola indicate that even relatively small changes in salinity have a large impact on zooplankton from this predominantly freshwater habitat. However, one should be cautious of extrapolating these patterns to higher salinities, particularly with regard to long-term trends such as climate change. In a scenario of increasing salinity due to rising sea levels, tidal lakes like Waihola will eventually become suitable habitats for more estuarine and marine taxa, and colonisation by these taxa will increase species richness and density (cf. Remane & Schlieper 1971, de Jonge 1974). These systems will then shift to estuarine patterns of functioning.

Changes in zooplankton community structure with increasing salinity, similar to those we report, have been reported in other freshwater-to-brackish ecosystems around the world (Table 2). These studies show that total zooplankton (Frey 1993, Green 1993, Hammer 1993, Jeppesen et al. 1994, Garcia et al. 1997, Ramdani et al. 2001a), cladoceran (Frey 1993, Green 1993, Ramdani et al. 2001a), rotifer (Green 1993, Green & Menengestou 1993), and copepod (Green 1993, Ramdani et al. 2001a) taxonomic richness all decrease with increasing salinity. In addition, zooplankton density decreases with increasing salinity in

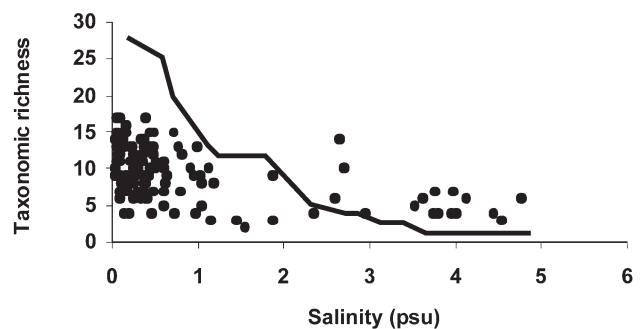


Fig. 8. Observed (points) and modelled (line) patterns of zooplankton taxonomic richness at different salinities in Lake Waihola. Modelled data are based on the abundance-weighted maximum salinity tolerances from Fig. 5 and Table 1

a number of Danish and Canadian brackish and freshwater lakes (Hammer 1993, Jeppesen et al. 1994). Field studies carried out along salinity gradients in single systems over time (longitudinal studies) show that zooplankton taxonomic richness and density decrease with increasing salinity (Grindley 1981, Egborge 1994, Siegfried et al. 1996, this study). This pattern was not observed in 4 Brazilian estuaries, however, where the high humic content and low pH of the inflowing blackwater rivers might have contributed to the unusually low abundance and taxonomic richness of zooplankton (Lopes 1996). In a South African estuary, zooplankton taxonomic richness declined along a salinity gradient from freshwater to ca. 2.0 psu, but increased as salinity increased from ca. 5 to 10 psu, stabilising at higher salinities (Grindley 1981). A similar pattern was proposed earlier as a general model describing taxonomic richness as a function of salinity; however, the higher salinity range of 5 to 7 psu was suggested as the salinity threshold delimiting the decline of taxonomic richness (Remane & Schlieper

1971). It has been suggested that both the mean salinity and the magnitude of temporal salinity variations are important in structuring the fauna of brackish coastal inland waters (de Jonge 1974).

Comparisons of the effects of cladocerans and copepods on pelagic food webs of lakes of different trophic condition show that shifts in dominance in the zooplankton from *Daphnia* to copepods could cause significant changes in food-web structure, matter and energy flow (Burns & Schallenberg 2001), and water quality. In Lake Waihola, high abundances of *D. carinata* were only recorded at salinities <0.4 psu. Where *D. carinata* was recorded at salinities >0.4 psu, it was found at very low densities, indicating its very low tolerance for salinity in this lake. *Daphnia* congeners have low upper salinity thresholds in other thalassic (ca. 2.0 psu, Jeppesen et al. 1994; ca. 1.8 psu, Moss 1994) and athalassic (ca. 2.5 psu, Ramdani et al. 2001a,b) systems. In some athalassic lakes, however, *D. carinata* has been recorded at salinities up to ca. 7 psu (Williams et al. 1990), illustrating that this species

Table 2. Effect of salinity on zooplankton taxonomic richness and abundance in various aquatic ecosystems. The salinity threshold is that corresponding to steepest decline/increase in taxonomic richness or abundance along salinity gradients, unless otherwise stated. (a): athalassic systems; (t): thalassic (marine-influenced) systems. Only those studies in which salinity gradients encompassed oligohaline (or subsaline) waters were included in the analysis. All salinity values converted to psu from other units are presented as ca. psu

System	Type of system	Zooplankton taxonomic richness	Zooplankton abundance	Salinity threshold	Source
<b>Survey studies</b>					
Danish lakes	Lakes (a)	Decrease	Decrease	<ca. 2 psu <sup>d</sup>	Jeppesen et al. (1994)
Australian, South African, Canadian, Iranian and German waterbodies	Various (a,t)	Decrease <sup>a</sup>		ca. 3 psu <sup>a,e</sup>	Frey (1993)
East African lakes	Inland lakes (t)	Decrease <sup>a,b,c</sup>		1.0 mS cm <sup>-1f</sup>	Green (1993)
Canadian prairie lakes	Saline lakes (t)	Decrease	Decrease	ca. 7 psu; ca. 30 psu	Hammer (1993)
Ethiopian water bodies	Water bodies (t)	Decrease <sup>b</sup>		ca. 2 psu	Green & Menengestou (1993)
North African wetland lakes	Shallow lakes	Decrease <sup>a,c</sup>		ca. 1 psu	Ramdani et al. (2001a)
<b>Longitudinal studies</b>					
Carapebus Lagoon	Lagoon (a)	Decrease			Attayde & Bozelli (1998)
Brazilian estuaries	Estuary (a)		Increase		Lopes (1996)
Lake Waihola	Tidal lake (a)	Decrease	Decrease	1.2 psu	This study
Swartkops Estuary	Estuary (a)	Decrease/increase		ca. 1 to 2 psu/ ca. 5 to 13 psu	Grindley (1981)
Onondaga Lake	Ionicly polluted lake	Decrease			Siegfried et al. (1996)
Lagos Harbour - Badagry Creek	Estuary (a)	Decrease <sup>b</sup>			Egborge (1994)
Fuente de Piedra	Temporary lake (t)	Decrease			Garcia et al. (1997)
<sup>a</sup> Cladocerans					
<sup>b</sup> Rotifers					
<sup>c</sup> Copepods					
<sup>d</sup> Threshold delimiting freshwater and brackish communities					
<sup>e</sup> Threshold delimiting subsaline from hyposaline waters based on zooplankton communities					
<sup>f</sup> Temperature of samples not specified					

complex (Hebert 1977) has the genetic and/or physiological potential to adapt to higher salinities in certain regions.

Our study shows that the zooplankton community of a low-lying, coastal, tidal lake is adversely affected by small increases in salinity levels. The salinities of some similar freshwater ecosystems are predicted to increase as a result of anthropogenic global climate change (IPCC 2001b, NZMfE 2001). The changes to zooplankton community structure that we recorded in Lake Waihola imply that there will be similar impacts on the community structure of coastal wetlands elsewhere in response to increases in salinity. These changes may further disturb the ecological functioning of these valuable and vulnerable ecosystems.

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