Lentic water types of Marion and Prince Edward Islands with comments on their zooplankton

O.B. Kok

Department of Zoology,
University of the Orange Free State, Bloemfontein 9301.

Zooplankton was obtained from 186 freshwater bodies sampled on Marion and Prince Edward Islands during the summer of 1974. For comparative purposes the lentic water types of the islands were classified into six categories, namely crater lakes, tarns, scarp lakelets, glacial lakes, post-glacial lakelets and elephant seal wallows. The main physico-chemical and morphological characteristics of each group are briefly outlined. Apart from a few insects, oribatids and oligochaetes, the freshwater fauna consisted of Entomostraca, notably the calanoid copepod Pseudoboeckella volucris. *Zooplankton abundance and species diversity are significantly correlated with the trophic status of freshwater bodies which, in turn, is a function of height above sea-level or distance from the sea. With the change from eutrophic to oligotrophic water bodies,* P. volucris *increasingly dominated the zooplankton while its sex ratio, with obvious implications on productivity, became more strongly skewed in favour of females. Previous reports on seasonality and habitat preferences of* Pleuroxus aduncus, Marionobiotus jeanneli *and* Tigriopus angulatus *are briefly elaborated on.*

Soöplankton van 186 varswatermassas is gedurende die somer van 1974 op Marion en Prins Edward eilande versamel. Vir vergelykingsdoeleindes is die lentiese watertipes van die eilande in ses kategorieë verdeel, naamlik kratermere, bergmere, eskarpmeertjies, glasiaalmere, post-glasiaalmeertjies en see-olifant moddergate. Die belangrikste fisiko-chemiese en morfologiese eienskappe van elke groep is kortliks aangestip. Afgesien van enkele insekte, oribate en oligochaeta het die varswaterfauna uit Entomostraca, veral die calanoïde copepoda Pseudoboeckella volucris, *bestaan. Soöplanktonrykdom en spesieverskeidenheid is betekenisvol gekorreleer met die trofiese status van varswatermassas wat op hul beurt 'n funksie van hoogte bo seespieël of afstand van die see is. Met die oorgang van eutrofiese na oligotrofiese watermassas domineer* P. volucris *die soöplankton in toenemende mate, terwyl die geslagsverhouding, met voor die hand liggende implikasies op produktiwiteit, al hoe meer oorkel ten gunste van wyfies. Vorige mededelings oor seisoenale voorkoms en habitatsvoorkeure van* Pleuroxus aduncus, Marionobiotus jeanneli *en* Tigriopus angulatus *word kortliks oor uitgewei.*

Introduction

Since the first South African scientific expedition to the sub-Antarctic Marion and Prince Edward Islands in 1965–66 (Van Zinderen Bakker *et al.*, 1971), yearly expeditions have been undertaken from 1971 onwards. As part of a long-term bioenergetics and mineral cycling programme, initial quantitative research mainly involved the terrestrial ecosystem (Croome, 1973; Smith, 1976a, 1976b) and primary production in different water bodies (Grobbelaar, 1974a, 1974b, 1975). Zooplankton studies were confined to work of a descriptive nature (Grindley, 1971; Smith and Sayers, 1971) and incidental reports of large concentrations in some freshwater bodies (Grobbelaar, 1974b; Huntley, 1971; Smith, 1977). The aim of the present study was, therefore, to obtain a better insight into the food cycles of the water ecosystem by concentrating on the biomass, distribution and ecological setting of zooplankton associated with different lentic water types.

Study areas

Marion (46°54'S, 37°45'E) and Prince Edward Islands (46°38'S, 37°57'E) are situated in the southern Indian Ocean approximately 2300 km south-east of Cape Town. As sub-Antarctic islands, the general meteorological conditions are cold (average annual temperature of 5,1°C), wet (average yearly precipitation exceeds 2500 mm) and windy (mean annual wind speed of about 27 km/h) (Schulze, 1971). Lying only 20 km apart, the islands are essensially similar in geology, topography and biology. Due to the lack of facilities on the smaller, uninhabited island (Prince Edward), most of the work reported here has been confined to Marion Island, a roughly oval island with an area of 290 km².

Materials and methods

During the fourth biological expedition to the islands (December 1973-May 1974), 271 water samples were collected from 186 different sites. Although the samples from Marion represent lentic water types from all over the island, the eastern area in the vicinity of the meteorological station was sampled more intensively (Fig. 1). Fourteen samples collected from Prince Edward Island were limited to freshwater bodies on the eastern coastal plain below an altitude of 100 m above sea-level.

In order to minimise the effect of a strong light stimulus in the vertical migration of zooplankton, water samples were usually collected before noon on cloudy mornings, no difficult task as the sky is obscured on average by more than three-fourths cloud cover throughout the year (Schulze, 1971). Each sample consisted of three litres of water (reduced to one-litre units in the tables) collected in four 750 ml glass bottles, usually from the edges of the water bodies. Whenever feasible, successive samples were taken at 50-cm intervals from the surface to a depth of 150 cm with a home-made apparatus working on the same principle as a Van Dorn water sampler. After sieving through a plankton net (280 μm mesh), the organisms were preserved in 4 per cent formaldehyde. In cases where excessive amounts of mud, debris and filamentous algae were present, the preservative and its contents were processed in a Retch KG shake and sieve apparatus before microscopical investigation. With the exception of a few damaged insects and broken exoskeletal parts belonging to the oribatid superfamilies Ameronothroidea and Liacaroidea, all invertebrates were identified to the species level and counted. *Pseudoboeckella volucris* Kiefer individuals, the most abundant species sampled, were also sexed.

Water temperature in the field was measured with a thermistor thermometer (YSI Model 54), while a Metrohm E 488 pH-meter was used to determine pH values.

Results

For comparative purposes the lentic waters of Marion and Prince Edward Islands were classified into six categories. A brief outline of these follows, the main properties of each group being summarised in Table 1. As no "lake" as such (Odum, 1971) occurs on the islands, the term is used rather loosely to indicate the larger water bodies.

Crater lakes: The approximately 130 conical hills on Marion Island mark the main centres of eruption belonging to the second volcanic stage in the island's geological evolution (Verwoerd, 1971). The cones, consisting of coarse

Table 1

Main characteristics of freshwater bodies sampled. Numbers in brackets refer to number of samples on which average values (followed by standard deviation and range) are based (Grobbelaar's 1974b data excluded)

Parameter	Crater lakes (18)	Tarns (43)	Scarp lakelets (20)	Glacial lakes (45)	Post-glacial lakelets (82)	Wallows (63)
pH	6,8±0,7	6,4±0,6	6,5±1,1	6,6±0,7	6,3±0,9	7,0±1,1
	5,8–7,5	5,7–8,4	4,9–8,5	5,4–7,9	5,4–9,0	4,4–9,6
Surface water temperature (°C)	8,5±2,4	8,7±3,7	9,5±2,7	8,4±1,6	9,7±1,8	13,0±3,0
	5,0–11,5	2,0–17,0	4,5–14,0	5,0–11,0	6,0–12,5	6,0–20,0
Conductivity (μS at 25°C)*	49,7±13,4	45,8±11,5	—	88,8±16,5	220,0±149,0	300,7±299,5
	35,8–69,5	30,0–66,0		47,0–110,0	48,5–565,0	57,0–1630,0
Total major ions (mg/l)*	24,7±5,7	21,7±3,1	—	47,0±10,5	134,7±73,5	175,2±155,2
(Na, K, Ca, Mg, Cl, SO_4)	18,4–37,4	15,4–26,7		19,6–65,8	21,9–248,8	34,5–535,6
Circumference (m)	226±247	130±97	164±99	273±207	146±147	20±26
	100–800	20–470	45–400	25–850	10–600	3–130
Altitude (m)	228±119	212±83	110±66	93±54	59±19	9±5
	50–350	150–450	50–150	50–100	20–100	1–30
Distance from sea (m)	2000±1099	2100±649	1100±333	700±525	400±373	75±30
	400–3100	700–3600	600–1700	200–1500	100–1600	10–100
Avian and/or mammalian influence	negligible	light	moderate	moderate	heavy	very heavy
With zooplankton (%)	100	70	80	85	92	71
Occurrence of main surrounding vascular plants (%)						
Aceana	25	15	30	30	22	—
Agrostis	38	93	90	96	75	44
Azorella	100	63	20	61	16	—
Blechnum	12	11	20	9	13	—
Cotula	—	—	—	—	5	35
Poa	—	4	—	30	14	70
Tillaea	—	—	—	—	18	9

*From Grobbelaar (1974b).

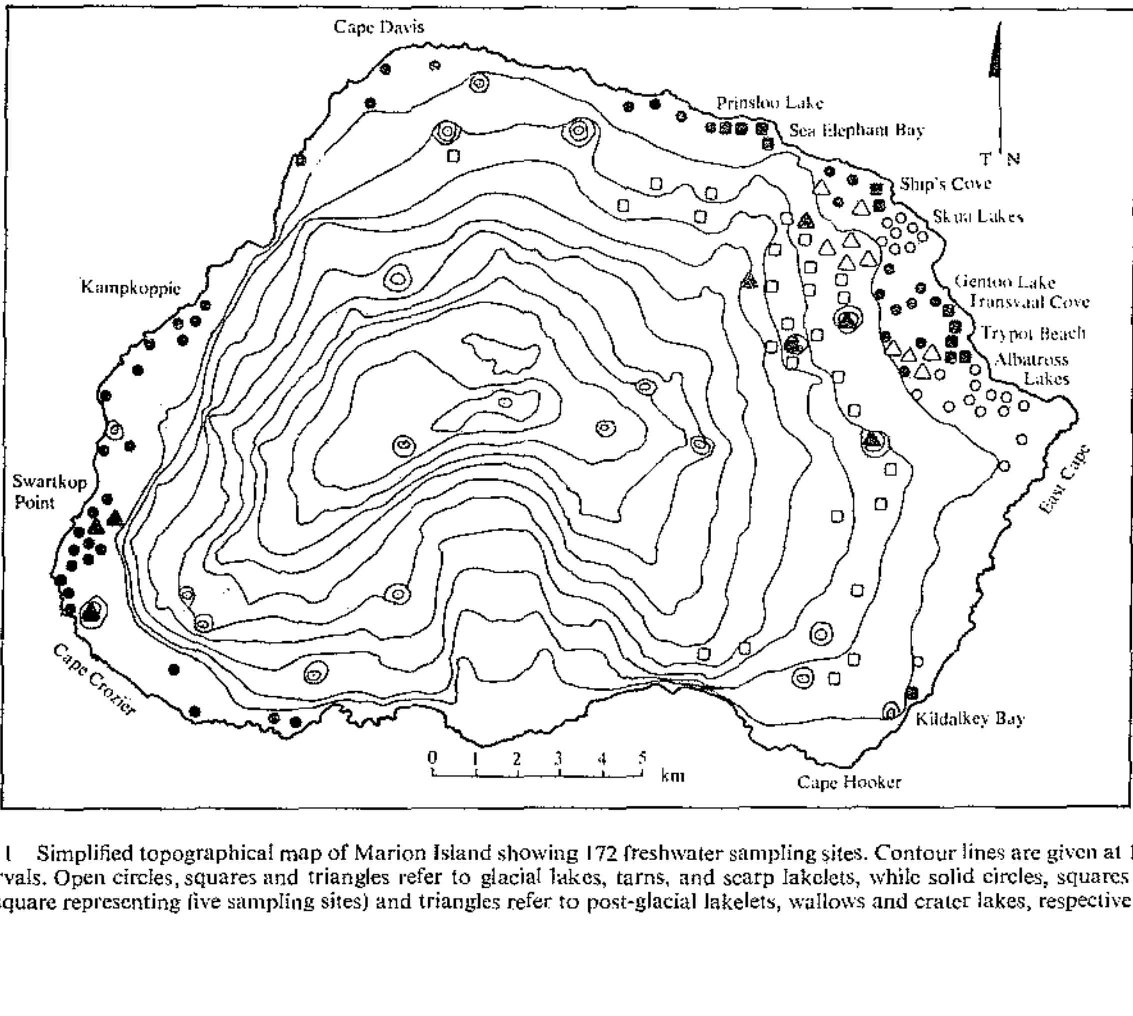

Fig. 1 Simplified topographical map of Marion Island showing 172 freshwater sampling sites. Contour lines are given at 100-m intervals. Open circles, squares and triangles refer to glacial lakes, tarns, and scarp lakelets, while solid circles, squares (each square representing five sampling sites) and triangles refer to post-glacial lakelets, wallows and crater lakes, respectively.

scoriae, are steep-sided and reach up to 200 m above their surroundings. Although many contain central depressions, none of the craters of the central highland contains any lakes (Grobbelaar, 1974b). Those with crater lakes (Fig. 2a), second only to glacial lakes as far as average surface area is concerned, are mostly restricted to the eastern coastal plain.

The eight crater lakes sampled averaged 228 m above sea-level, the highest mean altitude (but not distance from the sea) of the six categories distinguished. Within the craters, cushion plants (*Azorella selago* Hook. f.) represent the most important vascular plant community. In contrast to the other water bodies sampled, all crater lakes contained zooplankton. However, due to their low nutrient status resulting from their isolation, paucity of vegetation and soil within the catchment area and absence of major influence by birds or mammals, the zooplankton populations inhabiting the crater lakes were found to be rather sparse (Table 2), a fact also commented on by Huntley (1971).

Tarns: For the purpose of this study, all water bodies on the basaltic black lava flows at an altitude of at least 150 m are referred to as "tarns". Most of these are small and shallow, and are usually laterally drained through an *Agrostis magellanica* Lam. mire. In comparison to the other water bodies, tarns are situated the furthest from the sea. As a result, the effect of salt spray and influence by sea-going birds and mammals is slight. As indicated in Table 1, tarns show the lowest conductivity and total major ionic content of all freshwater habitats. They likewise have the lowest standing crop (Table 2) and, consequently, a lower percentage with zooplankton.

Scarp lakelets: Scarp lakelets, which provide useful intermediate stages in a few general trends to be discussed later, are situated at the boundary between the lava types of the first and second volcanic stages. Though relatively scarce, lakelets belonging to this category are easily distinguished by their black and grey lava borders on opposite sides. The rather high mean temperature of the surface water (Table 1) is perhaps associated with the greater heat absorption and conduction capacities of the black lava part of the water edge. *Agrostis magellanica* mires are the dominant plant communities in the immediate vicinity of the lakelets, but typical slope complex communities such as *Acaena adscendens* Vahl. herbfield and *Blechnum penna-marina* (Poir) Kuhn fernbrake are also well developed. Owing to their protected location, the lakelets are moderately influenced by birds such as giant petrel (*Macronectes halli* Mathews) and skuas (*Stercorarius skua* Brunnich), which often nest in the immediate vicinity, a fact reflected by the higher number of zooplankton per unit volume as compared to the previous water type (Table 2). No data on conductivity and chemical composition of the waters, represented by the ions Na, K, Ca, Mg, Cl and SO_4, could be obtained.

Glacial lakes: Shallow lakes, often clustered in groups like the Albatross and Skua Lakes (Fig. 1), are to be found on the old grey lava flows which have been subjected to glacial activity. On average, these lakes are the largest on the island (Table 1). Owing to the smooth and exposed topography of the grey lava, the vegetation surrounding the glacial lakes is mostly of an *Agrostis* mire type (Fig. 2b). Vascular plants such as *Acaena adscendens* and *Azorella selago* are scattered in the mires, but rarely form a conspicuous constituent. The presence of coprophilous *Poa cookii* Hook. on the shorelines is an indication of the light to moderate effect which foraging gulls (*Larus dominicanus* Lichtenstein), groups of non-breeding skuas (*S. skua*) and nesting wandering albatrosses (*Diomedea exulans* L.) have on the shore vegetation.

Post-glacial lakelets: Numerous small lakelets are formed in the rugged black lava flows of the islands (Fig. 2c). Large isolated lakes also occur, of which Prinsloo Lake is the largest individual water body on Marion Island. Others are clustered together in groups, for example the Kampkoppie and Swartkop Point Lakes on Marion's west coast. The latter lakes are

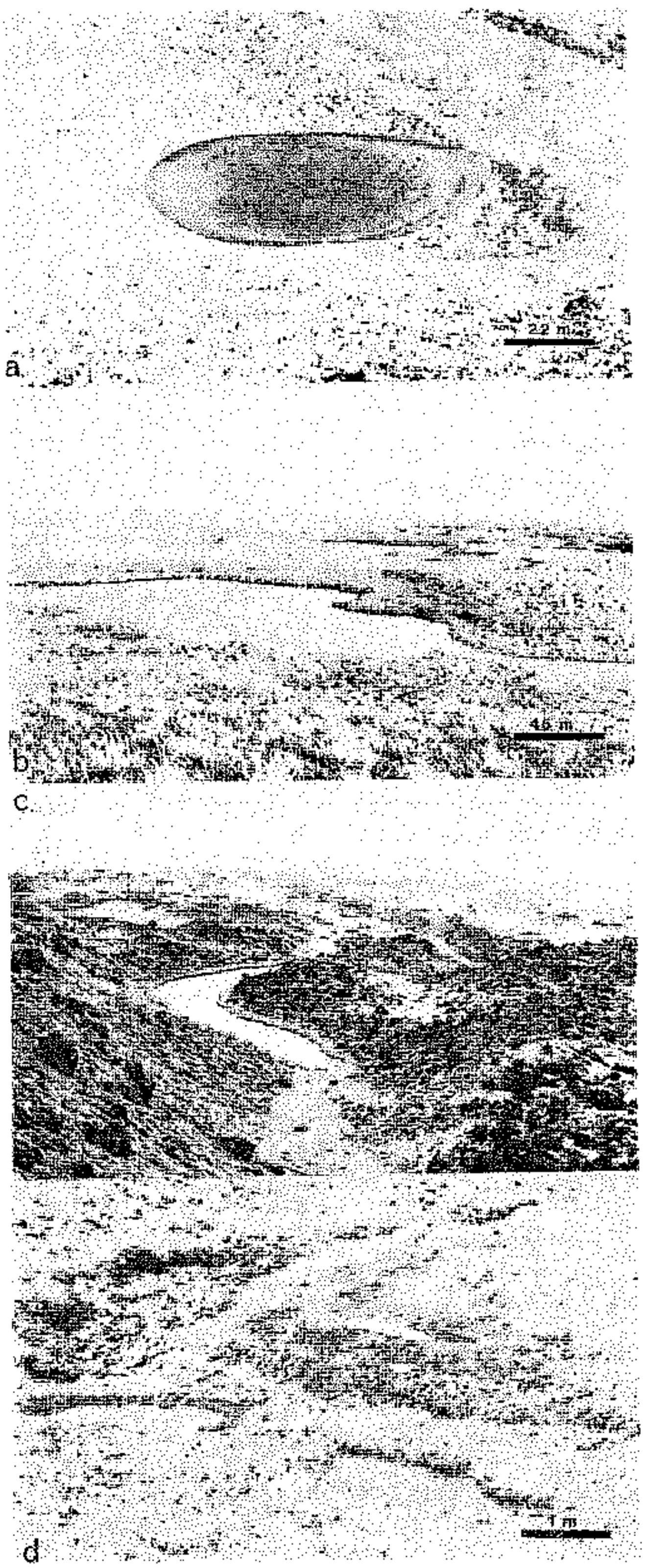

Fig. 2. Lentic water types of Marion and Prince Edward Islands. *a*, typical crater lake with narrow belt of shallow marginal water. Reddish scoriae mainly covered by cushions of *Azorella selago*. *b*, smooth topography of the glacial grey lava flow. Lake surrounded by an extensive stand of *Agrostis magellanica* mire. *c*, hummocky topography of a post-glacial black lava flow. Lakelet encircled by patches of *A. magellanica* mire. *d*, elephant seal wallows. Vegetation in immediate vicinity includes *A. magellanica*, *Cotula plumosa* and *Poa cookii*.

Table 2

Average number of zooplankton per litre surface water. Numbers in brackets refer to number of samples on which average values are based.

		Crater lakes (18)	Tarns (43)	Scarp lakelets (20)	Glacial lakes (45)	Post-glacial lakelets (82)	Wallows (63)
Alona		0,003	—	0,100	0,067	0,167	0,200
Daphniopsis		0,700	0,233	1,267	1,067	2,533	8,333
Halozetes		—	0,013	—	—	0,100	0,300
Ilyodromus		—	—	0,010	0,013	0,800	2,600
Marionobiotus		—	—	—	0,100	—	—
Microscolex		—	—	—	—	0,033	0,007
Pleuroxus		—	0,013	0,033	—	0,033	0,007
Podacarus		—	—	0,033	0,030	0,100	0,167
Pseudoboeckella	males	0,070	0,120	0,230	0,490	1,071	1,910
	females	3,530	2,980	3,670	4,443	6,596	7,190
Tigriopus		—	—	—	—	0,033	1,933
Insecta		—	0,013	0,033	0,067	0,067	0,100
Total		4,303	3,372	5,376	6,277	11,533	22,747

exposed to the almost ceaseless westerly winds which deposit appreciable amounts of sea-spray on the land. As a result most of the lakes are bordered by dense stands of *Cotula plumosa* Hook. f. and the halophytic *Tillaea moschata* DC. In contrast, the surrounding vegetation of the more sheltered water bodies on the eastern coastal plains of both Marion and Prince Edward Islands is dominated by *Agrostis magellanica* mires, but also includes a fair amount of cushion plants (*Azorella selago*), ferns (*B. penna-marina*), rosaceous dwarf plants (*Acaena adscendens*) and tussock grassland (*P. cookii*).

As shown in Table 1, the mean surface water temperature of the post-glacial lakelets is relatively high, a phenomenon which can be attributed to the extreme solar radiation absorption properties of the pitch-black lava depressions in which the lakelets are formed. It is also evident that the freshwater bodies of the two islands are generally acidic in nature, with the post-glacial lakelets showing the lowest pH values, partly as a result of the seepage of acid groundwater from the peaty shores. The fact that some of these lakelets are heavily influenced by birds and mammals, notably king penguins (*Aptenodytes patagonica* Miller), macaroni penguins (*Eudytes chrysolophus* (Brandt)), rockhopper penguins (*Eudytes crestatus* (Miller)) and elephant seals (*Mirounga leonina* L.), and that such waters are generally more acidic than any other freshwater type (Grobbelaar, 1974a, 1974b), is a contributing factor in this regard. The pronounced enrichment of the waters is also reflected by the relatively high mineral content and conductivity, a fairly large zooplankton standing crop, almost double that of the previous water type (Table 2), and a corresponding high number of lakelets containing zooplankton (Table 1). Extremely rich zooplankton populations consisting of 2624 and 2685 entomostracans respectively, were encountered in one-litre water samples collected on 4/3/74 from Gentoo Lake and on 14/2/74 from Prinsloo Lake.

Wallows: Large numbers of elephant seals annually visit Marion and Prince Edward Islands for breeding and moulting purposes. Owing to their considerable bulk, the seals cause the compression and erosion of peat, thereby forming a pattern of numerous small hummocks and hollows. The latter rapidly fill to a depth of half a metre or more with water from rain or lateral seepage (Fig. 2d). Depending on the number of seals involved and the period of occupancy mammalian activity eventually results in the deepening, enlargement and confluence of the wallows. Sites occupied by elephant seals are usually grouped together in areas close to the sea (mean distance 75 ± 30 m) where suitable landing sites (mean altitude 9 ± 5 m) are available, for example Sea Elephant Bay, Ship's Cove, Transvaal Cove and Trypot Beach, whence most of the water samples were collected. Coprophilous plants, notably *Poa annua* L. and *P. cookii* and to a lesser extent *C. plumosa*, are the dominant plants in such areas.

Certain physico-chemical and morphological trends are well illustrated by subdividing elephant seal wallows into three categories, namely: occupied; re-occupied and old unoccupied wallows. The first category is represented by water-filled depressions fringed by bare peat surfaces (Fig. 3a), while the second stage, resulting from prolonged intermittant seal activity, is characterized by the enlargement of hollows and the formation of ooze. Where no traces of recent seal activity were found, the wallows were considered unoccupied. Such wallows typically contain a permanent water-table carpeted by coprophilous plants such as *Callitriche antarctica* Engelm. ex, *Montia fontana* L. and *Ranunculus biternatus* Sm. (Fig. 3b).

In comparison with the other water types, the pH and surface water temperature of wallows are unusually high (Tables 1 and 2). According to Grobbelaar (1974a, 1974b) and Huntley (1971) the high pH values especially noticeable in small occupied wallows result from an extreme degree of elephant seal fertilization. Once a wallow has been vacated, however, the pH is gradually lowered by seepage of humic acids from the surrounding peat and leaching by rainfall, hence the large pH range. As for the relatively high average temperature, considerable radiant energy is absorbed by the

Table 3

Main characteristics of elephant seal wallows. Numbers in brackets refer to number of samples on which average values (followed by standard deviation and range) are based (Grobbelaar's 1974b data excluded)

Parameter	Occupied (24)	Re-occupied (12)	Unoccupied (27)
pH	7,5 ± 1,1 4,4—9,0	7,1 ± 1,1 4,9—9,6	6,9 ± 1,0 4,7—9,5
Surface water temperature (°C)	14,5 ± 2,6 9,0—19,0	11,3 ± 3,3 6,0—15,5	12,4 ± 2,6 9,0—20,0
Conductivity (μS at 25°C)*	478,0 ± 373,7 125,5—1630,0	129,3 ± 95,3 63,5—319,0	121,1 ± 78,9 57,0—315,0
Total major ions (mg/l)* (Na, K, Ca, Mg, Cl, SO_4)	235,0 ± 154,4 80,5—535,6	99,1 ± 110,4 39,1—323,7	83,5 ± 88,4 34,5—314,6
With entomostracans (%)	21	58	74
Entomostraca /l	3,0 ± 8,3 0,0—33,2	31,6 ± 42,5 0,0—117,4	48,4 ± 76,8 0,0—353,0

*From Grobbelaar (1974b).

Fig. 3. Elephant seal wallows of Marion and Prince Edward Islands. *a*, dark stained water and bare, compressed edges of a recently occupied wallow. The hummocks are covered by *Poa cookii* tussock grassland. *b*, *Callitriche antarctica* colonizing an unoccupied wallow. A dense cover of *Cotula plumosa* and *P. cookii* occupy the zone at the water edge.

dark-stained water which varies in colour from black to brown. While water temperatures are normally close to the prevailing air temperature, heat build-up in the dark surface water of occupied wallows in particular can result in temperature differences of up to 7 °C.

Since the wallows are subjected to marked enrichment, reflected by the high conductivity and mineral content (Table 1), they show by far the largest zooplankton standing crop, notably of entomostracans and oribatids (Table 2). Paradoxically, wallows are also responsible for the greatest number of water samples devoid of zooplankton, recently established wallows not having had the time to acquire a diverse biota (Table 3).

Discussion

A striking feature of the freshwater zooplankton of Marion and Prince Edward Islands is the fact that Entomostraca comprised 99 per cent of the total sample. The latter populations consisted of only seven of the nine previously reported species, namely *Alona weinecki* Studer, *Daphniopsis studeri* Rühe, *Ilyodromus kerguelensis* G.W. Müller, *Marionobiotus jeanneli* Chappuis, *Pleuroxus aduncus wittsteini* Studer, *Pseudoboeckella volucris* Kiefer and *Tigriopus angulatus* Lang, the harpacticoid copepod *Epactophanes richardi antarcticus* (Richters) and the cladoceran *Macrothrix hirsuticornis* Norman and Brady not being represented. Of the first-mentioned species, the calanoid copepod *P. volucris* comprised almost three-quarters of the nearly 38 000 individuals sampled. The remaining one per cent of the total sample consisted of an oligochaete, *Microscolex kerguelarum* Grube, two species of oribarid mites, *Halozetes fulvus* Engelbrecht and *Podacarus auberti* Grandjean, and a few unidentified insects.

From the summarised data presented in Tables 1 and 2, it is apparent that species diversity and zooplankton abundance are significantly correlated with conductivity ($r = 0{,}903$; $t = 3{,}639 > t_{0,05}$ and $r = 0{,}940$; $t = 4{,}768 > t_{0,01}$ respectively) and mineral content ($r = 0{,}911$; $t = 3{,}825 > t_{0,05}$ and $r = 0{,}923$; $t = 4{,}147 > t_{0,01}$ respectively) of the freshwater bodies. Since the trophic status of the waters is governed by the extent of vertebrate influence and the amount of salt-spray which, in turn, is a function of distance from the sea (Grobbelaar, 1974b, 1975), it follows that the distribution and abundance of zooplankton must also be correlated with distance from the sea or, for that matter, height above sea-level. This was, in fact, found to be the case ($r = 0{,}802$; $t = 2{,}686 > t_{0,05}$ and $r = 0{,}823$; $t = 2{,}898 > t_{0,05}$ respectively). Surface water temperature and pH conditions did not appear to influence the total zooplankton abundance.

P. volucris, numerically the most important species sampled, increasingly dominated the zooplankton with increasing height above sea-level. Although males averaged only 13 per cent of the total number of individuals, a clear relationship also existed between the sex ratio and average altitude. With the change from eutrophic to oligotrophic water bodies there is, namely, a decrease in the number of males relative to females. Judged by the total abundance and number of females with egg-sacs, this has an obvious effect on productivity.

Preliminary reports by Grindley (1971) and Smith and Sayers (1971) on entomostracan habitats on Marion Island, indicate that *T. angulatus* inhabits rock pools on the upper part of the sea shore, that *P. aduncus* might be unable to tolerate conditions in elephant seal wallows and that *M. jeanneli* might be restricted to streams or stream pools. In this study, however, the latter species, although of rare occurrence, was found in large glacial lakes at an average altitude of 93 m, while both *P. aduncus* and *T. angulatus* were collected in wallows as far as 100 m inland. The occurrence of a number of *I. kerguelensis* in all months sampled (January–May), also negates the suggestion by Smith and Sayers (1971) that this species could be restricted to austral winter conditions.

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Whale observations in the pack ice off the Fimbul Ice Shelf, Antarctica

P.R. Condy

Mammal Research Institute,
University of Pretoria, Pretoria 0002.

During January and February of 1976 and 1977 seal censuses were carried out in the pack ice off the Fimbul Ice Shelf, in the King Haakon VII Sea, Antarctica. These two censuses formed part of a series started in 1974 (Hall-Martin, 1974a; Wilson, 1975a; Condy, 1976a and 1977). Whales were observed during all four censuses, but only during the latter two was an attempt made to determine their density and investigate their distribution according to pack ice concentration. The results are presented here and, where possible, data from the 1974 and 1975 census voyages have been included. The areas censused are shown in Fig. 1.

Methods

During the seal censuses in 1976 and 1977, all whales within 400 m on either side of the ship were recorded. The whales were identified and their number, the date, time (local), and local pack ice concentration within 100 m of the whales were recorded. Observations were made from the ship's bridge 10 m above the waterline, and the limits of the 400 m census strips were estimated using a sighting board similar to that described by Siniff, Cline & Erickson (1970), but modified to enable delimitation of the 400 m limit. The ship's position was recorded every 20–40 minutes using an Omega navigational aid in 1976, and a Redifon RSN I satellite navigating unit in 1977. Cross-checks with positional plots from conventional navigation techniques were made as often as possible. The ship's erratic course and speed through the pack ice made dead reckoning of ship's position, projected from a

Table 1

Estimated density of minke whales and killer whales observed in the pack ice off the Fimbul Ice Shelf, Antarctica.

Date	Distance travelled (km)	Area censused (km^2)	Whales observed: minke	Whales observed: killer	Density (whales/km^2): minke	Density (whales/km^2): killer
Jan/Feb 1976	481,40	385,12	48	0	0,12	0
Jan/Feb 1977	720,43	576,34	76	14	0,13	0,02

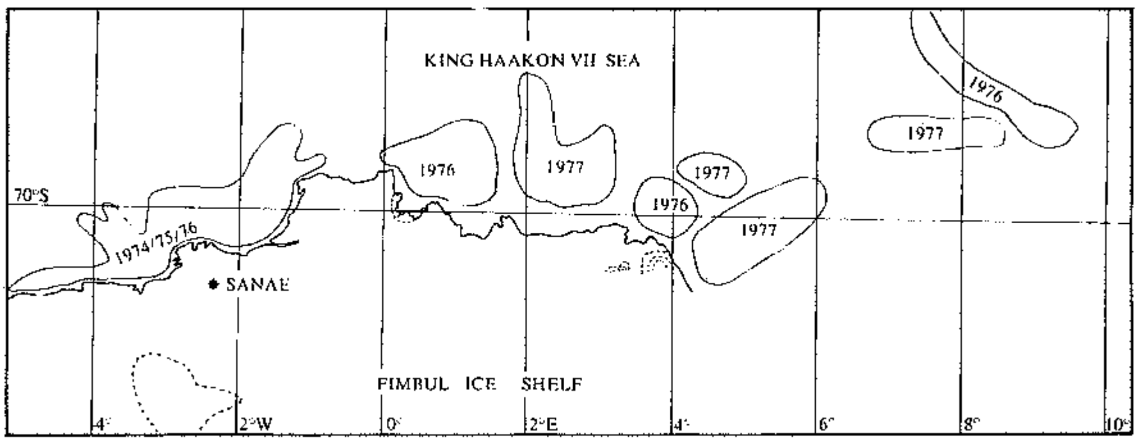

Fig. 1. Areas off the Fimbul Ice Shelf surveyed in January/February 1974–1977.