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Relationship of sediment toxicants and water quality to the distribution of platypus populations in urban streams

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Abstract. Live-trapping surveys recorded populations of the platypus, *Ornithorhynchus anatinus*, in 73% of 45 reaches in the Dandenong Creek and Werribee, Yarra, Maribyrnong, Bunyip, and Lang Lang River catchments near Melbourne, Victoria; however, many populations occurred at low density. Our study investigated the relationship between population status and water and sediment quality along 28 stream reaches, including 17 reaches supporting a population of *O. anatinus* and 11 reaches lacking a resident population. Stream attributes included surface water-quality variables (summer concentrations of dissolved O_2, total P [TP], NO_X, total Kjeldahl N [TKN], dissolved organic N, NH_4-N, and 50th, 75th, and 90th percentiles of suspended solids [SS]), concentrations of sediment toxicants (Zn, Pb, Cd, As, Cr, Cu, Hg, Ni), extent of catchment urbanization (as indicated by % imperviousness), and daily discharge. Reaches supporting a medium-density population (mean number of $\geq$0.5 adults or subadults captured per pair of nets set overnight) were characterized by significantly lower concentrations of streamwater TP, TKN, and SS (90th percentile), significantly lower Cd, Pb, and Zn in sediments, and significantly lower catchment imperviousness than reaches lacking resident animals. The maximum imperviousness associated with a population of *O. anatinus* was 11%, suggesting that this species is sensitive to urban-related change. Capture rate was not significantly correlated with median summer discharge, but was inversely correlated with streamwater TP and TKN. Further studies are needed to determine if pollutants may limit urban *O. anatinus* populations through direct toxicity or indirectly by pollutants reducing their benthic macroinvertebrate food resource.

Key words: platypus, urban streams, nutrient enrichment, sediment toxicants, water quality, biomonitoring, Melbourne.

The Australian biota comprises a high proportion of endemic species, including 74% of described mammals (Ceballos and Brown 1995). Among these is the platypus, *Ornithorhynchus anatinus*, which occupies lentic and lotic waterways along the eastern and southeastern coast of mainland Australia and throughout Tasmania (Grant 1992, Menkhorst 1995). *Ornithorhynchus anatinus* is a carnivore that feeds mainly on benthic insects, although it also consumes decapod and ostracod crustaceans, bivalves and gastropods, nematomorphs, and salmonid eggs. In nearly all areas studied to date, larval Trichoptera and/or Ephemeroptera compose a large proportion of the diet, whereas consumption of chironomid larvae is relatively low, possibly because of their small size (Faragher et al. 1979, Grant 1982, Munks et al. 2000). Based on studies in captivity and the wild, a nonbreeding adult *O. anatinus* consumes ~15 to 28% of its body mass/d to accommodate a daily energy expenditure of ~850 to 1100 kJ kg^{-1} d^{-1} (Krueger et al. 1992, Munks et al. 2000), with food intake of late-lactating females increasing to ~3× the daily consumption of nonlactating females (Holland and Jackson 2002). Animals forage by searching methodically along riffles and undercut banks, as well as by diving to the bottom of runs and pools (Serena 1994). Aerobic capacity limits underwater activity to ~1 min, which generally precludes feeding at depths >5 m (Evans et al. 1994, Bethge et al. 2001, 2003).

Effective conservation of biodiversity in urbanizing catchments requires an understanding of how well species adapt to altered flow regimes, channel morphology, pollutant concentrations, and habitat quality. Platypus popula-

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tions in the greater Melbourne area (human population ~3.5 million) have been studied since 1995 to identify factors affecting species distribution and abundance in urban streams. In the absence of comparable studies conducted elsewhere in Australia, our initial goal was to map where *O. anatinus* occurred in urban and outlying waterways, and to describe its population density and reproductive success. More recently, our research has focused on identifying bank and instream attributes that may influence platypus foraging patterns and selection of diurnal resting sites. Several significant relationships have been demonstrated between habitat variables and *O. anatinus* behavior in the Melbourne region, including a positive association between stable, undercut banks and distribution of feeding activity and burrows (Serena et al. 1998, 2001). Placement of *O. anatinus* burrows has been linked to abundance of overhanging riparian vegetation, and distribution of foraging effort has been linked to prevalence of riffle habitat and riparian tree cover, abundance of instream large woody debris and coarse particulate organic matter (CPOM), and the proportion of relatively coarse particles in streambed sediment (Serena et al. 1998, 2001). Sightings of *O. anatinus* have been positively correlated with abundance of overhanging vegetation and pool length and depth (up to 2 m) in the upper Macquarie River system in New South Wales (Ellem et al. 1998), and with cobbled substrate and water depth >1.5 m along the Hastings River (Grant 2004b).

The role of pollution in potentially limiting *O. anatinus* populations has not been previously addressed, apart from the issue of animal entanglement in litter (Serena and Williams 1998). The main purpose of our study was to determine whether sediment toxicants and/or physicochemical measures of surface water quality were related to occurrence and abundance of *O. anatinus* populations in urban streams around Melbourne.

Methods

Study area

The study area included streams across 6 catchments in southern Victoria: the Werribee (catchment area = 1450 km^2), Maribyrnong (1550 km^2), Yarra (3780 km^2), and Dandenong (325 km^2) systems draining into Port Phillip Bay, and the Bunyip (740 km^2) and Lang Lang (405 km^2) systems draining into Western Port Bay. Catchments are collectively contained within 3 physiographic regions: 1) Basalt Plains in the western and northwestern parts of the study area, 2) Sedimentary Hills in the northeast and east, and 3) Coastal Areas of consolidated dunes and swamp in the southeast (Savio 1991). A high proportion of the landscape has been subject to residential, industrial, or agricultural development, although tracts of reasonably intact forest remain, especially in the northeast and east. The region's human communities are serviced by separate stormwater and sanitary sewer systems, with septic tanks used to treat waste in some outlying districts.

Platypus population assessment

Surveys of *O. anatinus* were conducted using fyke nets (Iron Strand, Hvide Sande, Denmark), set in the afternoon and monitored at regular intervals through the night, the time when animals are most active. One pair of nets was set per site to detain animals moving either up- or downstream, with the length of each net suspended partly above the water so captured individuals could breathe. Animals were directed into the main body of the nets by panels of netting stretched across the entire width of the channel, and gaps under the netting were eliminated by securing the bottom edge with rocks (Serena 1994). Captured animals were marked uniquely using Trovan transponder tags implanted subcutaneously between the scapulae (Grant and Whittington 1991) and released at the point of capture after nets were removed from the water. Sex and age classes were assigned based on the size and appearance of calcaneal spurs on the hind legs, allowing recognition of 3 male classes (juvenile, ≤10 mo; subadult, 11–23 mo; adult, >23 mo) and 2 female classes (juvenile, ≤10 mo; adult or subadult, >10 mo) (Temple-Smith 1973).

Surveys were conducted from 1991 to 2002, with most trapping effort (96% of a total of 1467 net-nights; 1 net-night = 1 pair of fyke nets set overnight) occurring since 1995. Survey nets were set along 45 reaches (defined as a 4- to12-km stream section sampled at 5 to 9 sites, separated by 0.8- to 1.5-km intervals), including 1 reach in the Werribee River system, 4 in the

Maribyrnong River system, 29 in the Yarra River system, 7 in the Dandenong Creek system, 3 in the Bunyip River system, and 1 in the Lang Lang River system. To both maximize the area sampled and ensure that a high proportion of animals encountered nets in a given survey, the mean distance between consecutive survey sites (1.1 ± 0.3 km, mean ± 1 SE) was equivalent to the mean length of stream channel used by adults and subadults per foraging bout in the Melbourne area (1.1 ± 0.6 km; Serena 1994). Maximum depths during normal discharge were ~2.5 to 4 m, within the range of depths used by *O. anatinus*. Each reach was surveyed on 2 to 19 dates (5.4 ± 4.2 dates/reach, mean ±1 SE), with 95% of surveys conducted from September to May (spring through autumn). The status of *O. anatinus* for a given reach was assigned to 1 of the following 3 abundance categories based on capture frequency: 1) no resident population (animals not captured); 2) low density (mean number of <0.5 adults or subadults captured per site per night); and 3) medium density (mean number of ≥0.5 adults or subadults captured per site per night).

Environmental variables

Proportion of impervious area within the catchment (= imperviousness) upstream of reaches was estimated using methods from Pettigrove and Hoffmann (2003). Daily discharge data recorded by automated gauging stations from 1995 to 2002 were obtained from Melbourne Water's HYDSYS data base (Melbourne Water, P. O. Box 4342, Melbourne, Victoria 3001, Australia). Water-quality variables included dissolved O_2 (DO), the 50^{th}, 75^{th}, and 90^{th} percentiles of total suspended solids (SS50, SS75 and SS90, respectively), total Kjeldahl N (TKN) and its constituents, dissolved organic N (DON) and NH_4-N, nitrate/nitrite (NO_x), and total P (TP). Monthly measurements were made by Melbourne Water (www.melbournewater.com.au) using standard methods and quality assurance procedures (USEPA 1983, APHA 1989), or were obtained from the Victoria Water Resources Data Warehouse (Victorian Department of Primary Industries, www.vicwaterdata.net). Data on streamwater pH were compiled from the same sources in association with NH_4-N data to facilitate assessment of toxicity (ANZECC and ARMCANZ 2000). SS percentiles were calculated from measurements made throughout the year to ensure representative sampling of post-storm flows and base flow. Other water-quality variables and daily discharge were measured in the austral summer (January–March), which is Melbourne's driest season based on the mean number of rain events/mo (www.bom.gov.au), and also marks the energetically demanding period of late lactation and weaning for *O. anatinus* (Grant and Griffiths 1992). Except for Sassafras Creek (data collected in 1993 and 1994), water quality was evaluated from 1995 to 2002. This 8-y period is an appropriate time scale in relation to the life span of *O. anatinus*, which can extend up to 21 y in the wild (Grant 2004a).

Trace metals are generally the most prevalent class of toxic contaminants found in surface runoff and stream sediments in urbanized catchments (Novotny and Olem 1994). In our study, sediments were analyzed for 7 metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) and the metalloid As (hereafter called a metal). Surface samples (≤2 cm deep) of fine sediment (<0.063 mm) were collected 2 to 8 times per reach from 1994 to 2000. Samples were air-dried and digested (method 3051 in USEPA 1994) before metals were assayed. Concentrations of As, Cr, Cu, Pb, Ni, and Zn (detection limit = 1 mg/kg) and Cd and Hg (detection limit = 0.1 mg/kg) were measured using inductively coupled plasma/mass spectrometry (method 200.8 in USEPA 1994).

Data analysis

Environmental data were available for 35 reaches surveyed for *O. anatinus*, including 24 reaches where animals were recorded and 11 where none were captured. Seven reaches supporting a population within 3 km of the Yarra River were excluded from statistical analyses because their population status might have been influenced by proximity to the larger and less-degraded mainstem (Serena et al. 1998). Two-sample *t*-tests were used to compare mean DO, TP, TKN, and imperviousness between reaches supporting medium-density platypus populations and those lacking animals. Two-sample Kruskal–Wallis tests, the nonparametric equivalent of a *t*-test, were used to test for differences in median SS concentrations and metals between the 2 groups of reaches. Nonparametric Spearman's correlations were used to test for

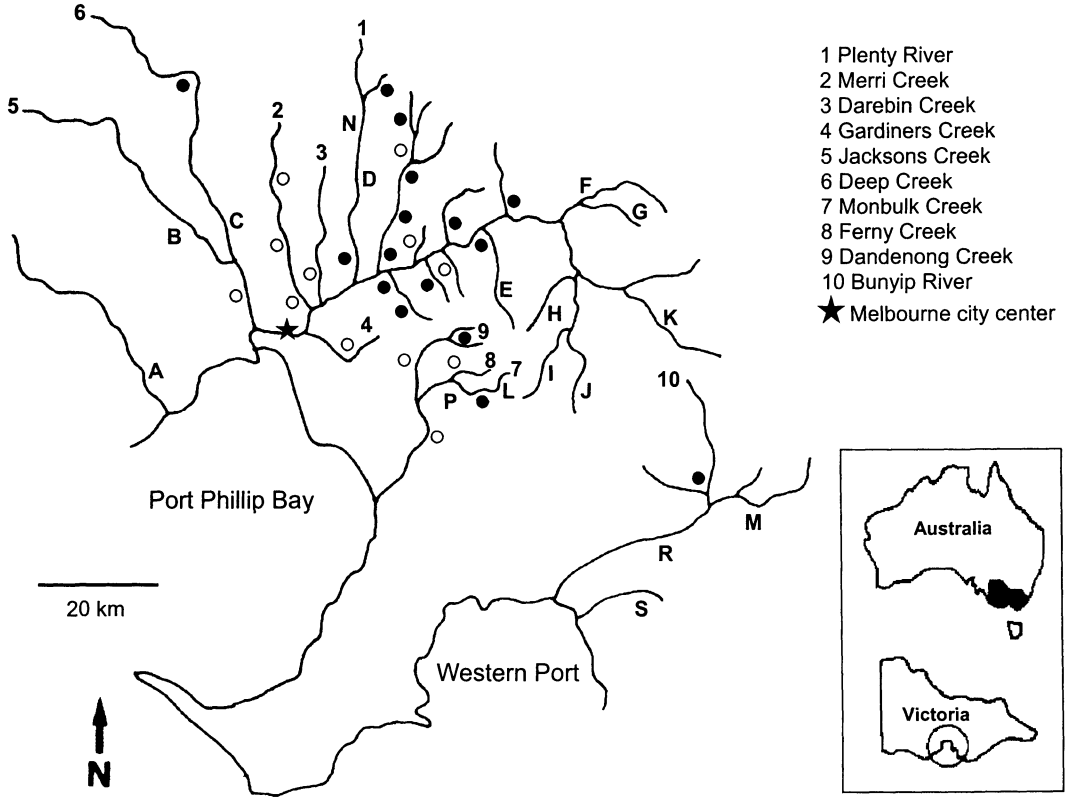

FIG. 1. Locations of the 45 stream reaches surveyed for the platypus, *Ornithorhynchus anatinus*, near the city of Melbourne, Victoria, southeastern Australia. Letters correspond to reaches supporting platypus populations in Table 1, closed circles indicate additional reaches supporting *O. anatinus* populations, and open circles indicate reaches lacking *O. anatinus*.

statistical dependence between environmental variables, and to correlate platypus capture rate and discharge. Given that several environmental variables were intercorrelated, simple linear regression was used to test the relationship between platypus capture rate and environmental variables that differed significantly in relation to animal presence/absence (James and McCulloch 1990). Prior to analyses, binomially distributed imperviousness data were arcsine-transformed, and SS90, Cd, Pb, and Zn data were $\log_{10}$-transformed to minimize influence of outliers and to correct for nonnormality (Zar 1984). α-level was set at 0.05 for all tests.

Results

Platypus population assessment

Ornithorhynchus anatinus was captured in 73% of the 45 reaches included in our study (Fig. 1). In the Yarra River catchment, animals occupied 100% of reaches sampled along streams joining the main stem >30 km upstream of the Melbourne city center ($n = 10$), but were captured in only 58% of reaches in tributaries closer to the city ($n = 19$). Animals were consistently recorded from 1995 to 2002 at sites located ~15 km from the city center along the Plenty River (1, Fig. 1), but they were not encountered closer to the city at sites along Merri, Darebin, and Gardiners creeks (2, 3 and 4, respectively; Fig. 1).

Animals were captured west of Melbourne in 1 reach of the Werribee River (A; Table 1, Fig. 1). Northwest of the city center, populations were recorded in the Maribyrnong River catchment along 1 reach of Jacksons Creek (5, Fig. 1) and 2 reaches of Deep Creek (6, Fig. 1), but not downstream of their confluence in the middle parts of the Maribyrnong River (one reach).

TABLE 1. Attributes of study reaches labeled with letters in Fig. 1 and associated populations of the platypus, *Ornithorhynchus anatinus*. Capture rate = mean number of adult or subadult *O. analinus* captured per site per night. NA = data not available.

Reach	Catchment	Reach length (km)	Median summer discharge (m^3/s)	Platypus capture rate	% females
Werribee River (A)	Werribee	7	0.234	0.62	48
Jacksons Creek (B)	Maribyrnong	9	0.079	0.60	50
Deep Creek (C)	Maribyrnong	6	0.021	0.57	75
Plenty River (D)	Yarra	7	0.022	0.52	54
Olinda Creek (E)	Yarra	8	0.076	0.95	56
Watts River (F)	Yarra	8	0.088	0.80	38
Graceburn Creek (G)	Yarra	4	0.009	0.67	75
Wandin Yallock Creek (H)	Yarra	6	0.026	0.60	100
Sassafras Creek (I)	Yarra	5	NA	1.25	50
Cockatoo Creek (J)	Yarra	6	0.097	1.00	20
Little Yarra River (K)	Yarra	9	0.716	0.86	42
Monbulk Creek (L)	Dandenong	6	0.053	1.28	55
Tarago River (M)	Bunyip	9	0.580	1.33	63
Plenty River (N)	Yarra	9	0.003	0.25	0
Monbulk Creek (P)	Dandenong	5	NA	0.41	8
Bunyip River (R)	Bunyip	11	1.464	0.40	0
Lang Lang River (S)	Lang Lang	10	NA	0.25	0

Southeast of Melbourne, animals occurred in the Dandenong Creek catchment along 3 reaches of Monbulk Creek (7, Fig. 1) and the uppermost reach of Dandenong Creek (9, Fig. 1), but not in lower Ferny Creek (8, Fig. 1) or the middle and lower reaches of Dandenong Creek. Animals were recorded in the Bunyip River catchment along 2 reaches of the Bunyip River (10, Fig.1) and one reach of the Tarago River (M; Table 1, Fig. 1), and in the Lang Lang River catchment along one reach of the Lang Lang River (S; Table 1, Fig. 1).

Platypus capture rates varied by 5x across the 17 reaches included in analyses (Table 1). Females composed ≥20% (median = 54%) of adults and subadults captured in the 13 medium-density populations, implying that these populations were capable of reproduction. In contrast, females were rarely or never recorded in the 4 low-density populations, suggesting little or no reproductive capacity. Capture rate was not significantly correlated with stream size, as indicated by median summer discharge ($r_s = 0.370$, $p = 0.197$, $n = 14$).

Environmental variables

There were no significant differences in mean summer concentrations of DO or NO_X between reaches supporting a medium-density *O. anatinus* population and reaches lacking a population (Table 2). However, imperviousness was significantly higher for reaches lacking a population than those with a medium-density population ($p < 0.05$); the same pattern was true for TP ($p < 0.01$) and TKN ($p < 0.05$). In absolute terms, mean imperviousness, TP, and TKN associated with medium-density populations were ~40, 60, and 70%, respectively, of the corresponding values from reaches where animals were not recorded. Median values for TP, TKN, and imperviousness were 0.048 mg/L, 0.55 mg/L, and 6%, respectively, for reaches with a medium-density population, 0.099 mg/L (range = 0.053–0.179 mg/L), 0.67 mg/L (range = 0.46–1.30 mg/L), and 2% (range = 2–18%) for the 4 reaches with a low-density population, and 0.098 mg/L, 0.80 mg/L, and 15% for reaches lacking a resident population.

Reaches supporting medium-density populations and those lacking populations did not differ significantly for SS50 or SS75 or in median sediment concentrations of As, Cr, Cu, Hg, or Ni (Table 3). However, SS90 was significantly higher in reaches lacking animals than in reaches with medium-density populations ($p < 0.05$); the same pattern was true for sediment concen-

TABLE 2. Mean (±1 SE) summer concentrations (mg/L) of dissolved O_2 (DO), total P (TP), NO_3/NO_2 (NO_x), total Kjeldahl N (TKN), and % catchment imperviousness in reaches supporting a medium-density platypus population and reaches lacking a resident population. Significant differences between reach group means tested by 2-sample *t* tests. ns = not significant ($p > 0.05$).

Variable	Medium-density population (*n*)	Range	No resident population (*n*)	Range	*p*
DO	7.9 ± 1.3 (13)	5.7–9.5	8.0 ± 1.5 (11)	5.4–10.9	ns
TP	0.058 ± 0.026 (13)	0.027–0.106	0.098 ± 0.039 (11)	0.035–0.176	0.006
NO_X	0.50 ± 0.62 (13)	0.04–1.83	0.30 ± 0.20 (11)	0.03–0.59	ns
TKN	0.57 ± 0.28 (13)	0.19–1.27	0.80 ± 0.27 (11)	0.40–1.17	0.049
Imperviousness	8 ± 4 (12)	1–11	19 ± 14 (11)	3–37	0.031[a]

[a] Following arcsine transformation

trations of Zn ($p < 0.01$), Pb ($p < 0.05$), and Cd ($p < 0.01$). In absolute terms, SS90 and metal concentrations in reaches with a medium-density population were 25% (Cd), <50% (Zn, Pb), and ~75% (SS90) of the corresponding median values from reaches lacking a population. Median concentrations of metals associated with the 4 low-density *O. anatinus* populations were 0.14 mg/kg (range = 0.05–0.2 mg/kg) for Cd, 15 mg/kg (range = 9–19 mg/kg) for Pb, and 38 mg/kg (range = 33.5–109 mg/kg) for Zn, whereas the corresponding median SS90 was 60.0 mg/L (range = 48–64 mg/L).

Six pairs of environmental variables that differed significantly between reaches with a medium-density population and those reaches lacking a population were significantly correlated. Concentrations of Cd, Pb, and Zn were highly intercorrelated ($p < 0.001$, $r^2 = 0.50$–0.74), as were TP and TKN ($p < 0.001$, $r^2 = 0.39$). In addition, imperviousness was positively correlated with sediment concentrations of Zn and Pb ($p < 0.005$, $r^2 = 0.29$–0.33). Capture rates were not correlated with 5 environmental variables that differed significantly between sites with and without *O. anatinus*, including imperviousness ($r^2 = 0.020$), SS90 ($r^2 = 0.001$), and sediment concentrations of Cd ($r^2 = 0.041$), Pb ($r^2 = 0.026$), and Zn ($r^2 = 0.033$). In contrast, platypus capture rates were negatively correlated with both TP ($r^2 = 0.339$, $p = 0.014$; Fig. 2A) and TKN ($r^2 = 0.252$, $p = 0.040$; Fig. 2B).

TKN mostly consisted of DON at all sites, with NH_4-N accounting for a mean 1 to 6% of TKN in reaches with a medium-density platypus population (range = 0.005–0.032 mg/L, $n = 12$), 1 to 5% of TKN in reaches with a low-density population (range = 0.005–0.036 mg/L,

TABLE 3. Median concentrations (mg/kg) of 8 metals in fine surface sediment, and 50th (SS50), 75th (SS75), and 90th (SS90) percentiles of suspended solids (SS, mg/L) in reaches supporting a medium-density platypus population and reaches lacking a resident population. Significant differences between reach group medians tested by 2-sample Kruskal–Wallis tests. ns = not significant ($p > 0.05$).

Variable	Medium-density population (*n*)	Range	No resident population (*n*)	Range	*p*
Zn	53 (12)	24–150	110 (11)	17–3000	0.008
Pb	15 (12)	8–55	32 (11)	5–490	0.025
Cd	0.1 (9)	0.05–0.25	0.4 (8)	0.1–3.0	0.007
As	4 (12)	0.3–12	4 (11)	2–24	ns
Cr	26 (12)	5.5–49	21 (11)	11–170	ns
Cu	12.5 (12)	5–21	16 (11)	7–210	ns
Hg	0.02 (9)	0.02–0.05	0.05 (9)	0.01–0.50	ns
Ni	12 (12)	6–36	17 (10)	6–110	ns
SS50	10.2 (10)	6–30	11 (10)	8–26	ns
SS75	19.7 (10)	12–38	26.5 (10)	17–79	ns
SS90	39.2 (10)	24–57	51.9 (10)	44–203	0.023

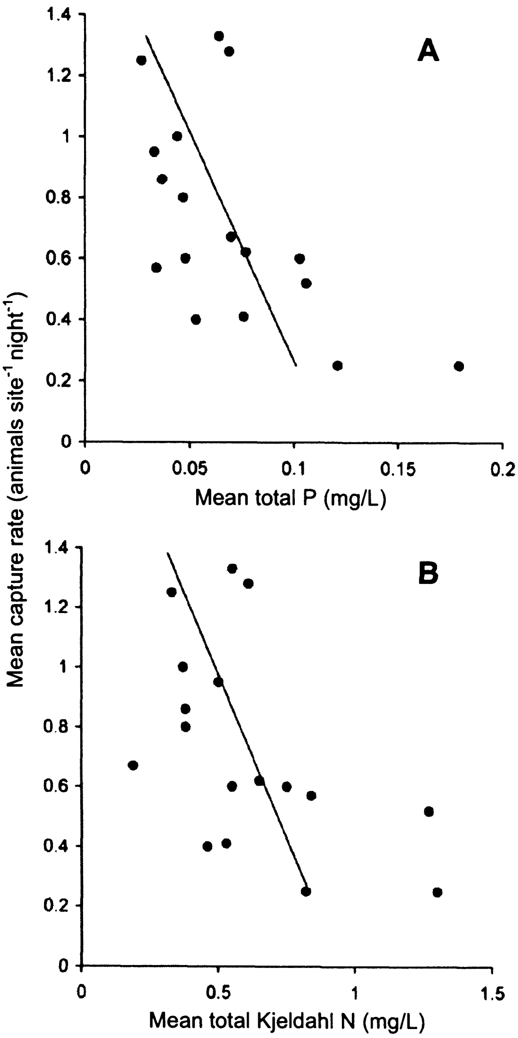

FIG. 2. Relationship between platypus density (as captures rate in reaches with low- and medium-density populations, see text) plotted against streamwater total P (A) and total Kjeldahl N (B).

n = 3), and 1 to 11% of TKN in reaches lacking a resident population (range = 0.005–0.130 mg/L, n = 11). Based on guidelines from ANZECC and ARMCANZ (2000), NH_4-N concentrations were considered potentially toxic in only 1 of 187 samples (0.5%) obtained from reaches supporting a medium-density *O. anatinus* population (Jacksons Creek), 1 of 42 samples (2.4%) from reaches supporting a low-density population (Lang Lang River), and 2 of 278 samples (0.7%) from reaches lacking a resident population (both from Gardiners Creek). Combined median concentrations of NO_X and NH_4-N were 0.26 mg/L (range = 0.06 to 1.84 mg/L) in 12 reaches with a medium-density *O. anatinus* population, 0.19 mg/L (0.17–0.56 mg/L) in 3 reaches with a low-density population, and 0.29 mg/L (0.05–0.72 mg/L) in 11 reaches lacking a resident population.

Discussion

Ornithorhynchus anatinus was seen regularly in the Yarra River within 5 km of central Melbourne as recently as the 1950s (Faithfull 1987). Our surveys indicate that the species persists in many streams in the greater Melbourne area, although few animals currently occur within a radius of <15 km from the city center. Platypus capture rate was not correlated with mean summer discharge in the perennial streams included in our study, suggesting that the importance of stream size is outweighed by other factors in limiting platypus population density. In particular, our results support the hypothesis that the status of platypus populations in reaches around Melbourne is influenced by catchment imperviousness and the distribution of surface water and sediment contaminants associated with urbanization.

Along with drainage connection, catchment imperviousness is an important determinant of increased storm runoff and decreased base flow (Leopold 1968, Walsh et al. 2005a), thereby contributing to urban stream degradation (e.g., Walsh et al. 2001, Hatt et al. 2004, Taylor et al. 2004). Several studies have suggested a stepped relationship between urban stream quality and imperviousness (reviewed by Walsh et al. 2005b), with a lower threshold defined by loss of sensitive stream elements and a higher threshold defined by progression to a highly degraded state. Estimates of critical boundary values for these two thresholds are ~8 and 12% (Wang et al. 2001), 10 and 25% (Schueler and Claytor 1997), or 12 and 30% catchment imperviousness (Klein 1979). In our study, reaches supporting a platypus population were characterized by a maximum of 11% imperviousness, suggesting that *O. anatinus* is appropriately classified as being sensitive to urban-related change at the catchment scale.

That catchment imperviousness varied significantly between reaches supporting a platypus population and those lacking animals does not preclude the possibility that other environmental variables may function more directly than imperviousness in determining platypus abundance. In our study, 3 water-quality variables, TP, TKN, and SS90, varied significantly with platypus population status in the Melbourne region. Of these, TP varied most strongly between reaches where *O. anatinus* were present or absent and, along with TKN, was negatively related to the rate of platypus captures per reach. Nutrient enrichment in streams and rivers near Melbourne has been linked to increased numerical dominance of small dipterans and oligochaetes over larger-bodied macroinvertebrate taxa more typically consumed by *O. anatinus* (Pettigrove 1990, Walsh et al. 2001). P enrichment in Melbourne's streams is also correlated with increased benthic algal biomass (Taylor et al. 2004). This shift in biotic conditions may reduce platypus foraging efficiency if high autotrophic biomass impedes prey detection or capture, as occurs in predatory fish (Glass 1971, Mittelbach 1981, Crowder and Cooper 1982, Werner et al. 1983).

The case for TKN being functionally related to *O. anatinus* abundance in its own right, as opposed to being a proxy for TP, is weak. TKN mainly consisted of DON, which is not readily assimilated by aquatic producers (Hvitved-Jacobsen 1986), and so is unlikely to have reduced *O. anatinus* population density by contributing to eutrophication. In theory, the NH_4-N component of TKN both provides primary producers with readily absorbed N and, depending on concentration, may reduce *O. anatinus* food resources by acting as a toxicant to macroinvertebrates (Hickey and Vickers 1994, Hickey and Martin 1999, Hickey et al. 1999). However, neither mechanism appears to have been an important influence on platypus abundance in our study area. NH_4-N did not contribute to consistently more assimilable N being available to producers in reaches lacking *O. anatinus* as compared with reaches supporting animals. As well, NH_4-N concentrations were potentially toxic in just 0.7% of samples obtained from reaches lacking *O. anatinus*, as compared to 0.9% of samples from reaches where animals occurred.

In contrast, suspended solids (i.e., SS90 in our study) provide a plausible mechanism linking platypus abundance and urbanization. Others have shown that increased SS caused by storms trigger catastrophic drift by macroinvertebrates, which may reduce benthic densities by >50% in 24 h (Culp et al. 1986). Such losses of macroinvertebrates, if significant in Melbourne streams, may directly reduce food resources for *O. anatinus*. In addition, fine sediment may impair platypus foraging efficiency: animals have been found to feed preferentially at sites dominated by substrates coarser than sand (Serena et al. 2001) or gravel (Grant 2004b).

Sediment concentrations of Zn, Pb, and Cd, which vary with local geology and quality and quantity of urban runoff near Melbourne (Pettigrove and Hoffmann 2003), also may contribute to variation in abundance of *O. anatinus* in urban streams. Exposure to each of these 3 metals can be lethal to freshwater vertebrates (Davies et al. 1976, Smith and Heath 1979, Calamari et al. 1980) and invertebrates (Rehwoldt et al. 1973, Thorp and Lake 1974, Anderson et al. 1980, Hatakeyama 1989), and elevated Zn (Weatherley et al. 1967), Cu, Pb, and Zn (Lake et al. 1977), and Cd, Cu, Pb, and Zn (Norris et al. 1982) have been linked to reduced macroinvertebrate diversity and abundance in Australian streams. Based on sediment-quality guidelines from MacDonald et al. (2000), "threshold effect concentrations" for Zn, Pb, and Cd (TEC, below which measurable adverse effects on benthic organisms are unlikely to occur), are 121, 35.8, and 0.99 mg/kg, respectively, whereas corresponding "probable effect concentrations" (PEC, above which adverse effects are likely to occur) are 459, 128, and 4.98 mg/kg, respectively. Assuming these metals influence platypus abundance in the Melbourne area by restricting macroinvertebrate prey, their maximum concentrations along reaches supporting this species are predicted to lie within, or possibly above, the range delimited by TEC and PEC values. In our study, this situation occurred for Zn (highest concentration for a medium-density population = 150 mg/kg) and Pb (55 mg/kg), but not Cd (0.25 mg/kg). However, without toxicological information describing accumulation and/or tolerance of Cd by *O. anatinus*, it remains possible that this species is adversely affected by sediment concentrations of Cd below those of its macroinvertebrate prey.

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