Altitude Separation and Pollution Tolerance in the Freshwater Crayfish *Euastacus spinifer* and *E. australasiensis* (Decapoda: Parastacidae) in Coastal Flowing Streams of the Blue Mountains, New South Wales

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The distribution of two freshwater crayfish species *Euastacus spinifer* (Decapoda: Parastacidae) and *E. australasiensis* were studied in the streams of the Blue Mountains, near Sydney. Forty sampling sites were established over a range of altitudes and upstream and downstream of sewage treatment plants. Sewage effluent was discharged directly from the treatment plants into the stream channels during the course of the study. Crayfish were sampled with electrofishing and a range of environmental variables estimated at each site. Crayfish were found at 60% of the sites sampled; *E. australasiensis* occurred at 7 sites (18%) and *E. spinifer* was found at 17 sites (42%). There were no sites in which both crayfish species occurred together. Both species occurred in small headwater streams, but *E. australasiensis* appeared to be limited to streams at altitudes above 810 m and *E. spinifer* to streams below this altitude. The actual mechanism for this altitudinal separation of the two species did not appear to be related to any particular substratum type, stream size, habitat type or cover. The highest crayfish density of either of the two *Euastacus* species recorded at any study site occurred at a site receiving treated sewage effluent. Crayfish occurred across the complete range of water quality measured at sites. The relative impact of other environmental disturbance (such as the introduction of exotic species and habitat destruction) on the conservation of crayfish populations is discussed.

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INTRODUCTION

There are 41 described species of the crayfish genus *Euastacus* (family Parastacidae) distributed throughout eastern Australia, 24 which occur in New South Wales. The biology and ecology of the majority of these species is poorly understood, with the possible exception of *E. spinifer*, which occurs near Sydney (Turvey and Merrick 1997a, b, c, d, e). The majority of *Euastacus* species have very localised distributions but a few species, such as the inland Murray River crayfish *E. armatus*, have very extensive distributions (Merrick 1993; Morgan 1997). However, even the distribution and abundance of species with extensive ranges can be reduced, probably through impacts such as habitat destruction, overfishing and pollution (Horwitz 1990).

Although the ranges of many crayfish species are restricted, they often overlap, but the co-occurrence of two species at exactly the same locality is uncommon (Morgan 1997). In general, there appears to be a narrow zone where both lowland and highland species coexist within any water course. In addition, because of the predominance of restricted ranges of *Euastacus*, it is difficult to find areas where two or more species occur over the same geological range. There have been several studies that have documented longitudinal separation within other genera of the Parastacidae. Richardson and Horwitz (1988) cite several examples of the local separation of burrowing crayfish in the genera *Engaeus* and *Parastacoides* and suggest that local topography is an important factor in separating species. There are fewer studies that show natural separation between stream dwelling crayfish in Australia. Horwitz (1994) noted that *Astacopsis franklinii* has been found in the middle and upper reaches of river systems in Tasmania which contain *A. gouldi* and suggests that some form of competitive displacement is the cause of the separation of these two species. However, Growns (1995) found no altitude separation between *A. tricornis* and *A. gouldi* in the streams of the Gog Range in Tasmania.

Two species of *Euastacus* co-occur within and around the Sydney region, *E. australasiensis* and *E. spinifer*. The distribution of *E. australasiensis* is much more restricted than that of *E. spinifer* but their ranges overlap in an area extending from near Wollongong, inland to the Blue Mountains and north to Gosford. The altitudinal range of both species is similar, from sea level to the higher parts of the Blue Mountains. Morgan (1997) suggested that the genus *Euastacus* could be divided into two main groups of species. *E. spinifer* is within the first group, which comprises species that occur at rather low altitudes and are medium to large in size. In contrast, *E. australasiensis* is part of the second group, which comprises small to medium-sized animals that generally occur at higher altitudes.

A large area of the natural range of *E. spinifer* around Sydney is now subject to urban development. Although the species also occurs in several National Parks located around Sydney these areas are known to have been modified to varying degrees and many waterways outside National Park boundaries are severely degraded (Merrick 1997). Merrick (1997) also suggested that the major threats to *Euastacus* populations were habitat destruction, fishing pressure, fires, chemical pollution, and introduced species. However, there is little information about the pollution tolerances of many crayfish species, and such information is needed for adequate management of crayfish populations.

The Blue Mountains area near Sydney is largely composed of National Parks, but urban development has increased rapidly over the last thirty years. The increasing human population in the Blue Mountains area has led to increases of urban rainfall runoff and treated sewage effluent discharge into stream headwaters. Because many sewage treatment plants (STPs) provide only secondary treatment for effluent the streams that receive these wastes have shown a deterioration in water quality (MWSDB 1987; Curry 1992; Wright 1992). These changes to water quality have caused impacts on the benthic macroinvertebrate communities (Wright 1992; Hardwick et al. 1994). In 1980, the Sydney Water Corporation (formerly the Sydney Water Board) assumed responsibility for both sewerage and water supply to the Blue Mountains area from the Blue Mountains City Council. The STPs that were a part of that sewerage system were in need of upgrading and amplification (MWSDB 1987). The Corporation began implementing an effluent management strategy for the Blue Mountains area, which included a program to remove STP effluents from the streams by diverting sewage from the small local STPs to a larger plant in the lower Blue Mountains (Currey 1993).

We sampled crayfish at sites in the Blue Mountains as a part of a three-year study commissioned to investigate the environmental effects of the Sydney Water Corporation's activities on the fish, fish habitats and fisheries of the Hawkesbury-Nepean River system (Pollard and Growns 1993; Gehrke and Harris 1996). Here we document the distribution of the two *Euastacus* species that occur in the Blue Mountains and indicate the pollution tolerances of each.

MATERIALS AND METHODS

The Blue Mountains study area is a dissected sandstone plateau lying approximately 50 km to the west of Sydney. The study area is drained by the Grose River to the north, the Coxs River to the south and west and tributaries of the Nepean River to the east. The Coxs River forms an important inflow to Lake Burragorang, the main potable water supply for Sydney (MWSDB 1987).

Most of the area lies in National Park and a strip of urban development lies along the ridge line between the Coxs and Grose River catchments. At the time of sampling there were ten STPs servicing the population of the area, some of which were overloaded and aging, with consequent impacts on water quality of streams receiving effluent (Currey 1993). Since this study, several of these sewage plants have been decommissioned.

A total of 40 sites were sampled for this study. Sites were chosen in areas upstream and immediately downstream of STPs (<1 km), far below STPs (approximately 5 km) and unimpacted reference streams. The majority of these sites have been sampled previously for their water quality characteristics (Currey 1992, 1993).

Crayfish were sampled in November 1993 using backpack electrofishing with two people. The first person operated the electrofisher, which stunned the crayfish, and these were collected by either the electrofisher operator or the second person with a dipnet. Twenty minutes of electrofishing was carried out at each site, moving upstream to cover a distance of approximately 100 m. The abundance of crayfish at each site was scored as 0 (no crayfish present), 1 (1 or 2 crayfish), 2 (3 to 10 crayfish), 3 (11 to 20 crayfish), 4 (21 to 50 crayfish) and 5 (greater than 50 crayfish).

At each site a variety of environmental variables were also recorded. These included a subjective estimate of the abundance (scale of 0 = absent to 4 = abundant) of substratum types (bedrock, boulder, cobble, gravel, sand, mud/silt, and clay), crayfish cover (rock, timber, undercuts and plant litter) and habitat types (pool and riffle). A visual estimate of average stream width and depth were also recorded for each site. The altitude of each site was obtained from 1:25000 topographical maps of the study area.

Water quality variables that were available for each site were calculated from the routine water quality monitoring data collected from the three months prior to sampling. The median values for turbidity, pH, temperature, conductivity, suspended solids, dissolved oxygen, total phosphorus, faecal coliforms, ammonium ions, total nitrogen, and the concentrations of iron and zinc were used as being indicative of the water quality of these sites that would have been affecting the populations of crayfish sampled. Sampling of the Cedar Creek site did not occur as a part of any monitoring program and as such the median values for water quality for this site were calculated from records of individual samples taken haphazardly over the past decade at this site. Water quality data were provided by Sydney Water.

RESULTS

Crayfish were found at 60% of the sites sampled (Table 1); *E. australasiensis* occurred at 7 sites (18%) and *E. spinifer* was found at 17 sites (42%). There were no sites in which both crayfish species occurred together. No crayfish were found at the remaining 16 sites (40%).

Crayfish had very low abundances below 280 m altitude. *E. spinifer* was found at sites between 145 m and 805 m and *E. australasiensis* occurred at all sites sampled between 810 m and 965 m (Table 1). Both crayfish were caught across a range of stream sizes (width and depths) and substratum types. However, both species occurred less often on sand or silt substrates (Table 2). *E. spinifer* occurred more often at sites with rock and litter cover than at other sites. Both species occurred at sites with a range of pool and riffle habitats.

TABLE 1

Subjective abundances of *E. australasiensis* and *E. spinifer* at sites (in order of altitude) sampled in the Blue Mountains. Sites are indicated as either reference (R) or located upstream (U), immediately downstream (I) or far downstream (F) of sewage treatment plants. Scores for crayfish abundance range from as 0 (no crayfish present), 1 (1 or 2 crayfish), 2 (3 to 10 crayfish), 3 (11 to 20 crayfish), 4 (21 to 50 crayfish) and 5 (greater than 50 crayfish). nd = not determined.

Site number	Site name	Type	Euastacus australasiensis	spinifer	Altitude (m)	Width (m)	Depth (m)
1	Lynches Crk	R	0	0	15	2	0.5
2	Winmalee Crk	F	0	0	20	5	0.6
3	Fitzgerald Crk	F	0	1	145	20	0.2
4	Lennox Crk d/s STP	I	0	0	170	1.5	0.4
5	Glenbrook Crk	R	0	0	170	10	0.5
6	Valley Heights Crk d/s STP	I	0	0	175	1	0.2
7	Valley Heights Crk	U	0	0	180	1.2	0.5
8	Fitzgerald Crk d/s STP	I	0	1	180	1.5	0.2
9	Lennox Crk u/s STP	U	0	0	190	1	0.3
10	Winmalee Crk d/s STP	I	0	0	220	10	0.5
11	Springwood Crk	R	0	1	260	8	0.3
12	Leura Falls Crk d/s STP	I	0	0	280	2	0.5
13	Linden Crk	R	0	2	290	10	1.0
14	Grose River	R	0	0	315	8	1.0
15	Govetts Crk	F	0	0	315	7	1.0
16	Wentworth Crk	F	0	2	370	12	1.0
17	Cedar Crk	R	0	2	375	2	0.3
18	Grose River	R	0	0	380	8	1.5
19	Urella Brook	R	0	3	390	1.5	0.5
20	Dawes Crk	R	0	2	430	5	0.8
21	Hathill Crk	F	0	2	435	2	0.7
22	Victoria Crk	R	0	2	435	10	0.3
23	Crayfish Crk	R	0	2	445	2.5	0.6
24	Bedford Pools	R	0	3	480	10	1.0
25	Grose River	R	0	0	485	15	0.5
26	Lawson Crk	R	0	2	500	2	0.5
27	Hazelbrook Crk d/s STP	I	0	0	540	1.5	0.2
28	Megalong Crk	R	0	0	605	2	0.4
29	Back Crk	R	0	0	630	1.2	0.8
30	Podgers Glen Crk	R	0	2	660	1.5	0.3
31	Blue Mountain Crk d/s STP	I	0	2	690	1.5	0.3
32	Blue Mountain Crk	U	0	4	730	1	0.2
33	Jamison Crk	R	0	3	805	nd	nd
34	Katoomba Crk	F	2	0	810	2	0.5
35	Yosemite Crk	R	3	0	850	2	0.5
36	Leura Falls Crk	U	2	0	895	1.5	0.3
37	Katoomba Crk d/s STP	I	1	0	940	1.5	0.3
38	Hathill Crk d/s STP	I	5	0	940	1.5	0.3
39	Katoomba Crk	U	3	0	960	2	0.2
40	Hathill Crk	U	4	0	965	1	0.2

TABLE 2

Substratum, cover and habitat characteristics at sites where *E. australasiensis* (n=7) and *E. spinifer* (n=17) were recorded. Scores range from 0 = absent to 3 = abundant

Variable	*E. australasiensis*		*E. spinifer*	
	Mean	Range	Mean	Range
Substratum				
Bedrock	2.3	(0–3)	1.5	(0–3)
Boulder	0.7	(0–3)	2.1	(0–3)
Cobble	0.3	(0–2)	1.2	(0–3)
Gravel	0.4	(0–3)	1.0	(0–3)
Sand	1.6	(0–3)	2.2	(0–3)
Silt	0.1	(0–1)	0.6	(0–2)
Cover				
Rock	2.4	(0–3)	2.6	(0–3)
Timber	2.1	(1–3)	1.7	(0–3)
Undercuts	0.3	(0–1)	0.2	(0–2)
Litter	1.4	(0–3)	2.1	(1–3)
Habitat				
Pool	2.1	(1–3)	2.7	(2–3)
Riffle	1.9	(0–3)	1.9	(0–3)

TABLE 3

Water quality characteristics at sites where *E. australasiensis* (n=7) and *E. spinifer* (n=17) were recorded.

Water quality variable	*E. australasiensis*		*E. spinifer*	
	Median	Range	Median	Range
Turbidity (NTU)	3.4	(2.6–4.4)	3.3	(0.5–10.4)
Conductivity (mS/m)	7.9	(5–13.1)	12.5	(3.2–44.5)
pH	6.9	(6.5–7.3)	6.6	(5.4–7.7)
Dissolved oxygen (mg/L)	9.0	(8.6–9.6)	9.2	(8.2–10.4)
Suspended solids (mg/L)	2.6	(1.5–3.7)	2.5	(0.5–11.2)
Total phosphorus (mg/L)	0.3	(0.1–1.1)	0.5	(0 – 6.0)
Nitrates (mg/L)	2.4	(0.7–6.0)	2.0	(0–17.3)
Ammonia (mg/L)	0.1	(0.1–0.3)	0.0	(0.0–0.3)
Faecal coliforms (CFU/100 ml)	276.0	(10–1060)	66.3	(1–291)
Faecal streptococci (CFU/100 ml)	25.5	(5–73)	175.8	(1–1367)
Iron (mg/L)	0.3	(0.2–0.4)	0.2	(0.0–0.6)
Zinc (mg/L)	0.1	(0.1–0.2)	0.1	(0.0–0.2)

Crayfish occurred at 4 of the 10 sites where STP sewage effluent was discharged (Table 1). The highest crayfish density of either of the two *Euastacus* species recorded at any study site occurred immediately below the Blackheath STP on Hathill Creek. Crayfish occurred across the complete range of nutrient and faecal streptococcus levels measured at all sites. However, crayfish were absent from sites having a zinc concentration above 0.2 mg/L, turbidity greater than 11 NTU, conductivity greater than 43 mS/m, suspended solids greater than 15 mg/L, ammonia greater than 0.43 mg/L, faecal coliforms greater than 1060 CFU/100 ml and iron greater than 0.58 mg/ (Table 3). In addition, crayfish were absent from sites with recorded oxygen levels less than 8 mg/L.

DISCUSSION

We have shown that the distributions of the two species of freshwater crayfish, *E. spinifer* and *E. australasiensis*, that have similar geographical ranges are separated according to altitude in the Blue Mountain streams. The actual mechanism for the altitudinal separation does not appear to be related to any particular substratum type, stream size, habitat type or cover. Both species occur in small headwater streams, but *E. australasiensis* appears to be limited to streams at altitudes above 810 m and *E. spinifer* to streams below this altitude. However, *E . spinifer* also occurred in small to large streams. In other parts of their geographic ranges both species occur at sites just above sea level, and therefore probably occur in a wide range of habitat types, and from small to large rivers. Our findings are supported by those of Horwitz (1994) who indicated that two species of *Astacopsis* occur at lower altitudes when they do not occur within the same river as *A. gouldi*. Horwitz suggested that the mechanism for the observed altitudinal separation is due to competitive displacement between species. Confirmation of this mechanism for effective separation of species within the same stream would require experimental manipulation of populations in the field.

Both *E. spinifer* and *E. australasiensis* occurred at sites that received treated sewage effluent. However, crayfish were absent from some sites that had higher concentrations of potentially toxic substances such as ammonia and heavy metals and lower concentrations of dissolved oxygen caused by the discharges of treated sewage effluent. However, we did not find crayfish at all unpolluted sites, which indicates that *E. spinifer* and *E. australasiensis* may have been absent from these sites, which had poor water quality, for other reasons. We have only used water quality data that were collected over three months before the sampling date. The absence of crayfish at some sewage treatment plants may have been related to water released from STPs at other earlier times or accumulated toxins in the sediments.

Merrick (1995) considered that the major threats to *Euastacus* populations were habitat destruction, fishing, fire, chemical pollution and introduced species. The *Euastacus* populations in the Blue Mountains are mainly located in National Parks, and are therefore unlikely to be affected by habitat destruction. However, as the human population increases in the Blue Mountains and nearby urban areas, the threats of fire and fishing are also likely to increase. Also, introduced aquatic species such as trout are present in some streams in the Blue Mountains. There may be direct impacts of trout on *Euastacus* populations, but the threat is increased because another introduced (inland) species of crayfish, *Cherax destructor*, is commonly used as bait for trout fishing. It is likely that the introduction of both trout and *Cherax* species could contribute to the decline of *Euastacus* species. We did not locate any *C. destructor* in the Blue Mountains in this study but the species does occur in other parts of the Lake Burragorang catchment (NSW Fisheries, unpublished data). Although the current populations of *Euastacus* in the Blue Mountains appear to be viable, there is the potential for a wide variety of impacts to cause a decline in their numbers. Effective management options such as those suggested by Horwitz (1990) and Merrick (1995, 1997) are therefore required to ensure the future viability of *Euastacus* in the streams of the Blue Mountains.

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