Preliminary assessment of freshwater crayfish as environmental indicators of human impacts in canyons of the Blue Mountains, Australia

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ABSTRACT

Canyoning has become a popular recreation activity in the Greater Blue Mountains World Heritage Area (Australia), and park management consider that the activity is having an impact on local fauna of the fragile canyon ecosystems. Although only limited data exist on the native freshwater crayfish that inhabit these canyons, it has been suggested that they have the potential to act as a rapid bioindicator of human impacts. As a preliminary assessment, we sampled crayfish from two canyons that received high visitation and two with low visitation. We recorded only a single species, *Euastacus spinifer* and this was found to occur at higher altitudes than previously recorded. There was no significant difference in crayfish abundance or size between visitation levels. There were, however, differences in crayfish abundance between individual canyons. Animals within a canyon had the same colour morph which we deduced to be genetic under selection pressure. We concluded that despite several identified problems, crayfish could, with appropriate baseline data, provide a rapid assessment method that would be a useful tool to management.

Keywords: recreational impacts, environmental monitoring, rapid assessment, canyon fauna, adventure tourism, adventure recreation, genetic variation

INTRODUCTION

There has been growth in recreation demand within protected areas in recent years (Cole 1996; IUCN 1996; Buckley, 2003; Harmon and Worboys, 2004). Although associated activities are often seen as self-financing (WTO, 1992), the upkeep of such areas represents a considerable financial outlay to governments, and conflict between conservation and recreation objectives may be a key problem for management (Amend and Amend, 1995; Wearing and Neil, 1999; Tyrväinen, 2004; Ahmad, 2007). Recreation in protected areas may, therefore, only be desirable if the level, type and management of the activities are appropriate and, in particular, if the 'recreational carrying capacity' is respected (Ceballos-Lascuráin, 1996; NPWS 2001; Turner, 2006). Although various planning approaches to management that focus on resolving conflicts have been developed (e.g., Stankey *et al*, 1985; Kuss *et al*, 1990; Giongo *et al*., 1994), all are hampered by difficulties in identifying appropriate ecological indicators that enable rapid quantitative assessment of visitor impacts (Buckley, 2003, Cole and Wright, 2004).

Despite their disproportionately high importance as focal points for recreation, the effects of recreation activities on aquatic ecosystems are considered to be less well understood than their terrestrial counterparts and the least understood aspect of carrying capacity considerations (Hadwen *et al*, 2006, 2008; Hardiman and Burgin, in press a). This is probably because changes in such environments are not as immediately obvious as they are in terrestrial systems (Kuss *et al*., 1990; Liddle 1997; Burgin and Hardiman, in review). Knowledge of the recreational impacts in freshwater lotic ecosystems is particularly limited (Abell *et al*., 2007; Vance-Borland *et al*., 2008; Johnston and Robson, 2009a), especially for mobile aquatic organisms (Kuss et al., 1990; Yount and Niemi, 1990; Downes *et al*, 1993). This is at least in part because historically research on anthropogenic effects has tended to focus on water quality, either direct (e.g., sewage effluent discharge) or indirect (e.g., agricultural runoff - Kuss et al., 1990; Hadwen and Arthington, 2003).

One recreational activity that has the potential to impact on aquatic ecosystems in protected areas is ‘canyoning’, a sport that is popular in the sandstone canyons of the Greater Blue Mountains World Heritage Area (Australia). This recreation involves a combination of walking, abseiling (rappelling), swimming and rock scrambling through narrow, deep, water-filled slot gorges, predominantly during the warm summer months (Hardiman and Burgin, in press, a).

We have previously explored the impacts of canyoners on these fragile ecosystems, using benthic macroinvertebrates (Hardiman and Burgin, in press, b), organisms widely used as surrogates of ecological condition of rivers and streams (e.g., Metzeling, 1993; Rosenberg and Resh, 1993). They have also been used to assess impacts of different sources of water pollution, including sewage effluent (e.g.; Wright *et al.*, 1995; Coa *et al.*, 1996; Growns *et al.*, 1997), and mine drainage (e.g., Faith *et al*, 1995; Malmqvist and Hoffsten, 1999; Sloane and Norris, 2003; Battaglia *et al.*, 2005). Although effective in identifying pollution (e.g., Wright and Burgin, 2009), the process of collecting macroinvertebrates from remote wildness areas, their transport and subsequent identification is time consuming, and requires substantial resources and specialist technical time and skills for identification. If a biological indicator of canyon ecosystem health could be identified that would be cost effective and efficient, preferably by non-specialist personnel in the field (e.g., canyoners) it would be an effective tool to underpin management decisions.

Freshwater crayfish have been suggested as a potential bioindicator since they are a ‘sentinel’ organism (Rosenberg and Resh, 1993). They are relatively long-lived among the freshwater invertebrates (Honan and Mitchell, 1995; Johnston and Robson, 2009a), and they have an important role in the food web (Horwitz, 1990). As a dominant member of the lentic macrozoobenthos (Johnston and Robson, 2009a) they provide crucial functions for ecosystem health, for example, habitat modification due to their foraging (Momot, 1995), reduction of macrophyte biomass (Nyström *et al*, 1996), alteration of patch dynamics of major sediment transport events (Statzner et al, 2003), and removal of carrion (Hardiman, pers. obs.). In the wilderness canyon streams of the Greater Blue Mountains World Heritage Area where there is a dearth of aquatic vertebrates, freshwater crayfish are the largest resident aquatic species. They may thus provide the opportunity for rapid biological field assessment of ecosystem health.

Of the many species of Australian crayfish only two, *Euastacus spinifer* Heller 1865 and *Euastacus australasiensis* Milne Edwards, 1837, inhabit the upland streams of the Blue Mountains region (Merrick, 1993; Morgan, 1997; Growns and Marsden, 1998). Although these two species occur sympatrically over part of their distribution, in the Greater Blue Mountains World Heritage Area they are considered to be separated longitudinally by altitude: *E. australasiensis* occurs above 810 m and *E. spinifer* below this altitude (Growns and Marsden, 1998). Casual observation during canyoning by the senior author suggested that crayfish were less abundant and/or smaller in canyons subject to high recreation traffic than in less popular canyons.

Based on these observations we undertook this study to 1) obtain a preliminary assessment of the suitability of crayfish as a rapid assessment bioindicator of wilderness stream health, and 2) provide baseline data on crayfish populations in the canyons sampled. The null hypotheses that we tested were that there was no difference in the abundance of freshwater crayfish, their size or weight in canyons with high and low numbers of canyoners passing through them. We also tested if the catch varied between the seasons of spring and autumn to determine if there was a most appropriate time to sample to encounter the maximum number of individuals.

SITE DESCRIPTION

The study was undertaken in the Blue Mountains National Park, located 50 km west of Australia's largest city, Sydney (Figure 1). The park comprises a deeply dissected plateau covering 247,000 ha with its highest point approximately 1,100 m above sea level. The underlying rock is generally soft quartz lithic sandstones of the Triassic Narrabeen Group (Department of Mines, 1966). Canyons are deep incisions in this landscape, formed by the erosive action of streams that has resulted in narrow and dark passages between sheer rock walls. There are at least 400 canyons known in the region (Jamieson, 2001), generally located within a range of 600 – 800 m above sea level within the headwaters of waterways. The canyon streams are typically 4^{th} order or lower (*cf.* Strahler, 1957), with a dominant substratum of small to medium cobbles, and some stretches of sand, gravel, exposed bedrock and boulders, and these streams can be described as 'perennial flashy' (Allan, 1995). Although conditions may vary between locations, the streams are typically well aerated, shallow at base flow, clear, mildly acidic and nutrient poor (Hardiman and Burgin, in press, b; Wright and Burgin, 2009).

Located within a world heritage area, distant from residential and industrial development, the canyons are well buffered from human impacts by extensive areas of natural vegetation. The only access is via walking, generally on informal and unformed footpads, usually over distances of at least several kilometers. The only anthropogenic impact is pedestrian recreation due to canyoners visiting the area. The canyons are otherwise in 'pristine' condition.

METHODOLOGY

The canyons surveyed were located within the same biome, and at altitudes between 680 - 900 m above sea level (Figure 1). Four canyons were sampled: two high trafficked canyons (Claustral Canyon, grid reference 591836 - 586833, altitude 690 – 680 m, Mt Wilson map 8930-I-N; Grand Canyon, grid reference 510723 - 515723, altitude 900 -880 m, Katoomba map 8930-I-S), and two low trafficked canyons (Dalpura Canyon, grid reference 504855 - 498852, altitude 900 – 880 m; Mt. Wilson map 8930-I-N; Nayook Creek, 502082 - 506087, altitude 800 – 790 m, Rock Hill map 8931-2-S (CMA, various). All four canyons were sampled over a four-week period during March and April 1998 (austral autumn). One of the high traffic canyons (Grand Canyon) was re-sampled in November 1998 (austral spring) to test for seasonal effect. High trafficked canyons received 80 - 90 visits weekly, and the low trafficked canyons received between 0 - 10 visits weekly (Hardiman and Burgin, in press, b).

On each occasion, six replicate sites per canyon were randomly selected from among pools that were a minimum area of 10 m^2, a maximum 1 m deep, and a minimum 50 m apart. These criteria were employed to exclude ephemeral puddles while maximising the opportunity of observing and capturing the resident crayfish.

Without disturbing the water, at each pool a 5 minute visual search was first undertaken by two researchers to count active crayfish. The researchers then entered the water for a period of 10 minutes and searched under boulders and/or logs and other flood debris (as appropriate) and captured as many crayfish as possible with a dip net. Captured crayfish were then measured to the nearest millimetre (from rostrum tip to posterior of the extended telson), and weight was recorded to the nearest 5 gm. Species was ascertained with the aid of the texts and keys of Merrick (1993) and Morgan (1997), and notes on the colour of individuals were made. Results were analysed by ANOVA using MINITAB software.

RESULTS

In the autumn sampling a total of 89 crayfish were observed and 56 of these were captured. Only crayfish larger than 50 mm were able to be reliably identified to species. All such animals were *E. spinifer* (Table 1). Analysis of variance showed that none of the three parameters measured (animal abundance, length or weight) differed significantly between canyons receiving high or low traffic (Table 2). Abundance did, however, differ significantly between individual canyons ($F = 4.28_{2, 20}$, $P = 0.03$). These results therefore support the null hypothesis of no difference between canyons receiving high or low traffic, but do suggest that some other, unknown factors specific to individual canyons affect crayfish abundance.

Within the high traffic Grand Canyon, 9 crayfish were observed and 8 captured in spring compared with 18 observed and 5 captured in autumn, a total of 27 observed and 13 captured: all were *E. spinifer* (Table 3). There was no significant difference between seasons for any of the three parameters (Table 4).

Crayfish colour varied among canyons: all crayfish were bright orange in Grand Canyon and Nayook Creek; brown with orange and/or a blue tinge on the ventral surface and chelae in Claustral and Dalpura canyons. There was no within-canyon colour variation.

DISCUSSION

Freshwater crayfish as surrogates for ecosystem health

Our results support the null hypothesis that there is no difference in the abundance, size or weight of crayfish in canyons receiving high, and those receiving low levels of canyoner trampling. These results contrast with previous research that has shown that trampling is detrimental to invertebrates, for example in shallow zones of lowland aquatic systems (e.g., Liddle and Scorgie, 1980), marine rocky foreshores (Keough and Quinn, 1998), and mangrove forests (Ross, 2006). In each of these studies there was a negative impact on resident macroinvertebrate assemblage, and typically they were slow to recover. Blue Mountains National Park management has also suggested that canyoning (*cf*. trampling) has a detrimental impact on the biota of the area of the current study

(NPWS, 2001).

In contrast to these observations, our initial research on macroinvertebrates in these canyons (Hardiman and Burgin, in press b) showed that there was no statistical difference in the macroinvertbrate community between high and low traffic canyons. On closer investigation (i.e., more frequent sampling), however, we did find that trampling had an immediate detrimental impact on the macroinvertebrate assemblage but within 2 weeks the impact had dissipated, most likely due to re-invasion from adjacent untrampled areas of the canyon (Hardiman and Burgin, in review). An explanation for the apparent resilience is the pattern of visitation to the canyons. Canyons are effectively only visited by humans on weekends in the warmer months (Hardiman and Burgin, in press a, 2010), but not in the hottest periods of when bushfires are potentially a hazard in the surrounding bushland (pers. obs.). The current frequency and/or intensity of trampling may therefore not provide a sufficiently high impact on resident species (macroinvertebrates or freshwater crayfish) to have a sustained impact on the animals at current levels of human impact. We therefore remain ambivalent on the potential for crayfish to act as surrogates for human disturbance in upland streams. This needs further investigation beyond our pilot study with a larger number of canyons sampled more intensively.

Differences in freshwater crayfish between canyons

We did observe a difference in crayfish abundance among canyons. Patterns of habitat use by freshwater crayfish are poorly understood, especially among sympatric species

(Jones and Bergey, 2007; Johnston and Robson, 2009a). Although a number of habitat-related factors have been correlated with freshwater crayfish species distribution, for example, substratum type (Kutka *et al*, 1996; Barbaresi *et al*, 2007; Benvenuto et al, 2008), riparian shading (Smith *et al,* 1996; Naura and Robinson, 1998), submerged woody debris (Usio and Townsend, 2000), aquatic macrophytes (Rabeni, 1985), and water velocity (Kutka *et al*, 1996; Usio and Townsend, 2000), there is limited understanding of the effects of physical disturbance, especially human-induced, on their abundance and health.

There was no evidence that the variation in crayfish numbers among canyons was due to water quality. Physiochemical water parameters in the canyons are within the Australian and New Zealand Environment Conservation Council (ANZECC and ARMCANZ, 2000) guidelines for ecosystem protection in New South Wales upland streams, and all sites that Hardiman and Burgin (in press a) studied across high and low trafficked canyons had equivalent, 'pristine' water quality.

Johnston and Robson (2009a) found that the distribution of five sympatric species in the Grampians National Park, Victoria, was directly related to habitat type and the environmental and physicochemical variables that characterised such habitats. Although they did not specifically investigate animal abundance they found that a high percentage of boulders was the best correlate with crayfish absence. It was assumed that boulders were acting as a surrogate for a range of environmental and physicochemical variables. Although not quantified in the current study, the substratum of Blue Mountains canyons is typically a mix of large boulders, cobbles and patchy sand substratum with occasional woody debris, and the canyons are subject to frequent, forceful bed scouring by flash floods that may restructure the canyon over several kilometres. Because of these frequent major events that restructure the substrate sometimes over considerable distances, we do not consider that the differences in substrate at a specific time would determine the overall distribution of crayfish within a canyon.

Factors that may influence crayfish abundance among canyons include the relative amount and/or type of allochthonous vegetation/detritus suitable for grazing, hydrology, underlying rock type, shelter sites, or simply random chance. Within these naturally low nutrient environments with scant vegetation, the differences could also be due to food availability. The observation that crayfish inhabited pools both with and without visible detritus, in areas with limited vegetation does not support such a suggestion.

We observed that there were colour differences between canyons, but not between pools within a canyon. Most freshwater crayfish taxa have some-intra species variation in colour (Merrick, 1993; Morgan, 1997), and our observations may be interpreted as environmental differences among canyons. While there is some geological variation, this occurs both within and among canyons (Hardiman and Burgin, in press b) and, as indicated, water quality is similar across canyons (e.g., pH, conductivity, turbidity), and is within the natural range for pristine upland streams of the area. Since canyons generally have steep-sided rock walls, are located within rugged terrain and widely dispersed within the landscape there would be, at most, extremely limited opportunity for exchange of individuals between canyons. Genetic drift within such small isolated populations would play a role in the genetic make-up of a population within canyons. We therefore assume that the colour differences were due to genetic isolation of populations within canyons, and not environmental variation. There is some support for this suggestion. *Cherax destructor* has a high degree of inter-population morphological and genetic variability among physically separated populations (Campbell *et al*., 1994). Although based on limited data, there is some evidence that there are also genetic differences among *E. spinifer* populations and there is substantial morphological variation in the Blue Mountains region. Henrisson (1994) studied this variation in *E. spinifer* from five localities across New South Wales, including two from the Blue Mountains area. He found considerable variation among populations reflected in his erection of a sub-species (*Euastacus kremnobates*) for his Blue Mountains' populations (Wentworth Falls).

Although not quantified, there may have been some selection for specific colour morphs: dark brown body colour occurred in pools within canyons that had a greater amount of leaf litter substrate (Claustral and Dalpura canyons), and orange with clearer, sandy substrates (Nayook and Grand canyons). Despite frequent restructuring of habitats within canyons due to flash floods (Hardiman and Burgin, in press b), this would not exclude selection in response to predation within canyons that would ultimately result in cryptic colour morphs, and thus over time support the phenotypic divergence among canyons.

Observations on seasonal sampling

We found no statistical difference in crayfish abundance between austral autumn and spring in the Grand Canyon site. This was probably associated with equivalent water temperature in both seasons (10^0C). Johnston and Robson (2009a) also found that season did not affect distribution of five sympatric species of Australian crayfish.

Mating of the two Blue Mountains species occurs in late autumn, and the females carry eggs over-winter before hatching, usually in spring (Merrick, 1993; Morgan 1997). Although gravid females have been observed in the study area as late as mid-summer (Hardiman, pers. obs.), the only terrestrial encounter with an animal during the study was a gravid female in spring.

Gravid females have compromised mobility, and it can therefore be assumed that they change their behaviour during the colder winter months, when canyon water temperature falls to around 3-5^0C (Hardiman and Burgin, in press b) to limit exposure to predators and to optimise incubation conditions for their eggs, and although not sampled during this period, it is assumed that this would be the most difficult season to find the freshwater crayfish. Such low winter water temperatures are also difficult and potentially unsafe for sampling, as nearly all canyons can only be traversed by swimming.

Since there was no statistical seasonal variation in abundance, to avoid interference during the mating period and while females are carrying eggs, we consider that late summer and early autumn would the most appropriate time of the year to sample freshwater crayfish in the upland stream environment of our study.

Comment on the distribution of the crayfish of the Blue Mountains

The observation that only *E. spinifer* was present in the canyons sampled supports the finding of Growns and Marsden (1998) that the two species do not have a sympatric distribution. Finding *E. spinifer* at altitudes up to 900 m does, however, extend the species' range to higher altitude than previously recorded.

CONCLUDING REMARKS ON THE EFFICACY OF CRAYFISH AS BIOINDICATORS IN A CANYON ENVIRONMENT

This study was primarily undertaken as a preliminary assessment to determine if crayfish could be an appropriate bioindicator of environmental quality, and we used as the basis of our investigation the hypotheses that crayfish would be less abundant and/or smaller in high trafficked, compared to low trafficked canyons due to trampling by canyoners. Our results were not conclusive, however we did confirm that freshwater crayfish do meet some of the criteria for use as a rapid assessment bioindicator (*cf*. Rosenberg and Resh, 1993). They proved easy to catch and quantify. They also appear to be temporally stable, making their abundance more predictable and therefore potentially reliable for monitoring environmental change temporally. Such temporal stability has also been confirmed in other Australian studies of freshwater crayfish (e.g., Johnston and Robson, 2009a). As canyon streams are generally free-flowing all year (although some pools within individual sites may occasionally become temporarily isolated), there appears to be limited risk of the detection of resident crayfish being affected by a need for the animals to escape dry periods by burrowing, although this would be an issue for some species inhabiting seasonal streams and wetlands (Jones and Bergey, 2007; Johnston and Robson, 2009a, b).

The current research was successful in establishing baseline data on freshwater crayfish populations in the canyons sampled. These data could underpin assessment of ecosystem health by effectively any interested canyoner, particularly if the 'community' assessment component was restricted to a visual count of the number of animals present in pools. The rapidity of such an assessment tool would be in direct contrast to the substantially greater effort and resources required to use macroinvertebrates as surrogates of environmental health in equivalent habitats.

As a basis for management decisions, we recommend that baseline data should be collected across canyons with regular visitation to monitor changes over time. Since Hardiman and Burgin (2010) identified that around 80% of canyoning activity is concentrated in 20 popular canyons, and a visual count of animals within a pool would extend a canyon trip only minimally, the resources required to undertake regular assessments of high and low trafficked canyons would be cost effective. We therefore recommend that this preliminary study should be expanded to 1) confirm that freshwater crayfish do provide a useful surrogate for environmental health of the canyons; and 2) if so that park management should investigate using canyoners who are already largely relied upon to self-manage the canyons (see Hardiman and Burgin, 2010), to volunteer to count freshwater crayfish in late summer/early spring each year as a basis for at least some monitoring of the canyon environment.

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Table 1: Summary results of abundance, length and weight of the freshwater crayfish *Euastacus spinifer* between two high and two low trafficked canyons of the Greater Blue Mountains World Heritage Area with six pools sampled in each canyon, during March-April, austral autumn 1998.

	High traffic canyons	Low traffic canyons	All canyons
Number of crayfish observed per pool ~~(n = 89)~~			
Mean	2.6	4.8	3.7
Minimum	0	0	0
Maximum	6	12	12
Standard deviation	1.9	3.8	3.1
Length (mm) of crayfish captured per pool ~~(mm) (n = 56)~~			
Mean	70.7	69.6	69.9
Minimum	46	22	22
Maximum	140	180	180
Standard deviation	28.6	26.2	26.6
Weight (gm) of crayfish captured ~~(gm)~~ per pool ~~(n = 56)~~			

Mean	20	25	23.7
Minimum	5	5	5
Maximum	100	245	245
Standard deviation	25	38.2	35.0

Table 2: Summary of ANOVA results to investigate differences in abundance, length and weight of the freshwater crayfish *Euastacus spinifer* between two high and two low trafficked canyons of the Greater Blue Mountains World Heritage Area with six pools sampled in each canyon during March-April, austral autumn 1998 (* = significant <0.5)

Parameter	Source	SS	df	MS	F	P
Abundance	Traffic (High/Low)	30.38	1	30.38	1.04	0.42
	Site (Canyon)	58.42	2	29.21	4.28	0.03*
	Error	138.17	20	6.91		
	Total	226.96	23			
Length	Traffic (High/Low)	572.33	1	572.33	1.11	0.40
	Site (Canyon)	1033.94	2	516.97	0.30	0.74
	Error	34266.42	20	1713.32		
	Total	35872.68	23			
Weight	Traffic	504.17	1	504.17	0.95	0.43

(High/Low)					
Site (Canyon)	1059.32	2	529.66	0.67	0.52
Error	15872.52	20	793.63		
Total	17436	23			

Table 3: Summary results of abundance, length and weight of the freshwater crayfish *Euastacus spinifer* in the high traffic canyon Grand Canyon with six pools sampled in each ~~between~~ season of austral autumn and spring, 1998.

	Autumn	Spring
Number of crayfish observed per pool ~~(n = 27)~~		
Mean	3	1.5
Minimum	1	0
Maximum	6	4
Standard deviation	2.1	1.6
Length (mm) of crayfish captured ~~(mm) (n = 13)~~per pool		
Mean	103.6	81.8
Minimum	75	65
Maximum	140	95
Standard deviation	24.2	13.1
Weight (gm) of crayfish captured ~~(gm) (n = 13)~~per pool		

Mean	44	18.8
Minimum	20	5
Maximum	100	30
Standard deviation	32.7	8.8

Table 4: Summary of ANOVA results of abundance, length and weight of the crayfish *Euastacus spinifer* in the high traffic canyon Grand Canyon between austral autumn and spring, 1998.

Parameter	Source	SS	df	MS	F	P
Abundance	Season	6.75	1	6.75	1.90	0.20
	Replicates	35.5	10	3.55		
	Total	42.25	11			
Length	Season	1468.99	1	1468.99	4.56	0.06
	Replicates	3540.70	11	321.88		
	Total	5009.69	12			
Weight	Season	1961.73	1	1961.73	4.49	0.06
	Replicates	4807.5	11	437.05		
	Total	6769.23	12			

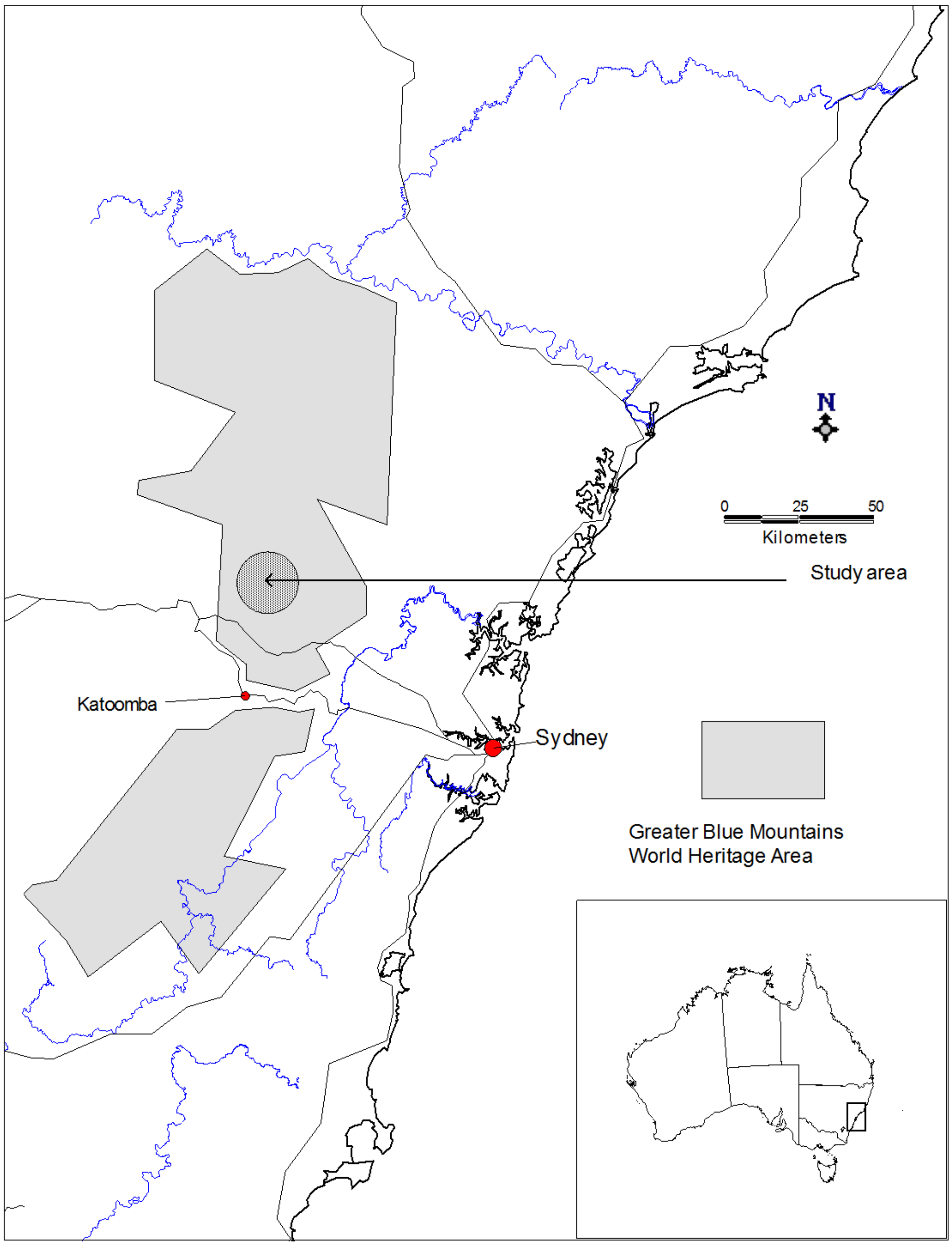

Figure 1: Location of the study area for the study of the freshwater crayfish *Euastacus spinifer* in the Greater Blue Mountains World Heritage Area, Australia.