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# Single-species sampling in Tasmania: an inefficient approach to invertebrate conservation?

*Robert Mesibov*[A,F], *Kevin J. Bonham*[B], *Niall Doran*[C], *Jeffrey Meggs*[D], *Sarah Munks*[E], *Helen Otley*[E] *and Karen Richards*[E]

[A]Queen Victoria Museum and Art Gallery, Wellington Street, Launceston, Tasmania 7250, Australia.
[B]School of Geography and Environmental Sciences, University of Tasmania, GPO Box 252-78, Hobart, Tasmania 7001, Australia.
[C]Department of Primary Industries, Water and Environment, GPO Box 44A, Hobart, Tasmania 7001, Australia.
[D]Forestry Tasmania, GPO Box 207B, Hobart, Tasmania 7001, Australia.
[E]Forest Practices Board, 30 Patrick Street, Hobart, Tasmania 7000, Australia.
[F]To whom correspondence should be addressed. Email: mesibov@southcom.com.au

*Abstract.* In recent years the distributions of a number of geographically restricted Tasmanian invertebrates have been carefully mapped by single-species sampling (SSS). We review 29 such projects targeted at 16 species. The average return of new locality records was only one per 1.3 person-days in the field. In almost all cases the SSS was aimed at improving the knowledge base for invertebrate conservation, and the principal end users of the results have been land managers, not biologists. It is suggested that more of the limited resources available for intensive fieldwork be directed to sampling functional groups of taxa, rather than single species, in areas prioritised by need for land management advice.

## Introduction

Since the early 1970s, field studies in Tasmania have been generating large numbers of locality records for non-marine invertebrates. Invertebrate collecting efforts over the past 30 years can be broadly categorised by focus: taxonomic group, target area, ecological hypothesis, or single-species distribution. In practice, of course, the boundaries between such categories will always be somewhat blurred, but the division is a useful one.

In group-focused sampling, specialist collectors have travelled widely throughout Tasmania in search of particular invertebrate groups, e.g. burrowing crayfish (Horwitz 1990), caddisflies (Neboiss 1977), centipedes (Mesibov 1986), earthworms (Kingston 2000), freshwater snails (Ponder *et al.* 1993; Ponder and Avern 2000), stoneflies (Hynes and Hynes 1980), terrestrial amphipods (Friend 1987) and water mites (Cook 1986). The usual aims were to compile a statewide inventory of species in the group, to record habitat information and to produce coarse-scale distribution maps.

In area-focused sampling, a wide range of invertebrate taxa have been collected (sometimes by non-specialist collectors) in circumscribed areas or habitats of special interest. The three largest area-focused surveys to date have been in south-western Tasmania: in the neighbourhood of a proposed hydro-electric project (Hickman and Hill 1978; Richardson and Swain 1978), at 12 well-scattered rainforest sites (Coy *et al.* 1993) as part of the National Rainforest Conservation Program, and in numerous Tasmanian caves (Eberhard *et al.* 1991). The aim, as in group-focused sampling, was to produce species lists, but the taxonomic boundaries of the lists were greatly expanded and the extent of sampled habitats greatly restricted.

A third major source of specimens and records has been hypothesis-focused sampling, in which selected taxa are collected in ‘treatment’ and ‘control’ areas to test for treatment effects. Recent hypothesis-focused surveys have looked for effects of clearfell harvesting on lucanid beetles (Michaels and Bornemissza 1999), moorland burning on arthropods collected by sweeping (Greenslade and Driessen 1999) and plantation forestry on velvet worms, millipedes, land snails and carabid beetles (Bonham *et al.* 2002). The Monitoring River Health Initiative (Oldmeadow *et al.* 1998), a large-scale survey program in which aquatic macroinvertebrates were collected in ‘relatively disturbed’ *v.* ‘relatively undisturbed’ catchments in Tasmania, can also be placed in this category.

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Beginning in the late 1980s, a fourth kind of sampling became commonplace. In single-species surveys, field workers have attempted to determine the complete distribution of a particular invertebrate species, generally one suspected of being a short-range endemic. Although there is nothing new in principle about such surveys, the level of support for single-species sampling (SSS) in recent years has been unprecedented. In this paper we review 29 SSS projects for 16 Tasmanian non-marine invertebrates. We note that SSS results have principally been used to assist in land management, and we argue that SSS is an inefficient way to gather information of value to land managers interested in conserving the largest possible number of invertebrates on particular blocks of land.

## Methods

The 16 species considered here are listed systematically in Table 1: four land snails, three velvet worms, four crayfish, a millipede, and four lucanid beetles. We selected these 16 species because they have been the subject of successful search efforts aimed at producing reasonably complete and reliable distribution maps. A further species satisfying these criteria, the nymphalid butterfly, *Oreixenica ptunarra*, has been excluded because local extinction has made irrelevant a significant number of pre-SSS localities (Neyland 1992). We are, of course, aware that specialists have searched for new localities for other species of native, non-marine invertebrates in recent years, but searchers have sometimes invested substantial field effort with very little return. For example, the 1992 search for a rare hesperiid butterfly, *Antipodia chaostola leucophaea*, occupied 26 field days but yielded only a single specimen from a previously known locality (Neyland and Bell 2000).

**Table 1. Systematic list of species whose Tasmanian distributions were mapped in the studies reviewed in this paper**

All species are Tasmanian endemics except the two marked with an asterisk. 'Conservation status' is the formal status recorded in the schedules of the Tasmanian *Threatened Species Protection Act 1995* as of 27 June 2001.

| Species | Conservation status |
|---|---|
| Gastropoda : Stylommatophora | |
| Caryodidae | |
| *Anoglypta launcestonensis* (Reeve, 1853) | Not listed[1] |
| Helicarionidae | |
| *Helicarion rubicundus* Dartnall & Kershaw, 1978 | Rare |
| Punctidae | |
| **Miselaoma weldii (*Tenison-Woods, 1877*)* | Endangered |
| Rhytididae | |
| **Tasmaphena lamproides* (Cox, 1868) | Rare |
| Onychophora : Peripatopsidae | |
| *Ooperipatellus cryptus* Jackson & Taylor, 1994 | Rare (susceptible) |
| *Tasmanipatus anophthalmus* Ruhberg *et al*., 1991 | Endangered |
| *Tasmanipatus barretti* Ruhberg *et al*., 1991 | Rare (susceptible) |
| Malacostraca : Decapoda : Parastacidae | |
| *Astacopsis gouldi* Clark, 1936 | Vulnerable |
| *Engaeus orramakunna* Horwitz, 1990 | Vulnerable |
| *Engaeus spinicaudatus* Horwitz, 1990 | Endangered |
| *Engaeus yabbimunna* Horwitz, 1994 | Vulnerable |
| Diplopoda : Polydesmida : Dalodesmidae | |
| *Lissodesmus alisonae* Jeekel, 1984 | Not listed |
| Insecta : Coleoptera : Lucanidae | |
| *Hoplogonus bornemisszai* Bartolozzi, 1996 | Endangered |
| *Hoplogonus simsoni* Parry, 1875 | Vulnerable |
| *Lissotes latidens* Westwood, 1855 | Endangered |
| *Lissotes menalcas* Westwood, 1855 | Vulnerable |

[1]Formerly listed as Vulnerable; delisted in 2000.

In each case we sought to quantify how SSS had improved knowledge of species distribution. For conservation purposes, the most appropriate distribution measure is area of occupancy, i.e. the area actually occupied by a species within its range envelope (IUCN 1994). However, this measure is unavailable for most of the 16 species, and for none of the species are there area of occupancy estimates at each stage in the accumulation of locality data. To facilitate comparisons we have therefore chosen two simpler distribution measures: (*1*) number of 1-km Universal Transverse Mercator (UTM) grid squares containing a record, which we call a 'one-kilometre-square area' (OKSA); and (*2*) area of the minimum convex polygon (MCP) enclosing all records.

One-kilometre-square areas were calculated directly from localities, which in Tasmania are routinely specified as UTM grid squares. Localities used in this study were most often 100-m squares estimated from 1 : 25000 scale maps, but smaller squares were sometimes available from global positioning system (GPS) output data. Several species were recorded many years ago from less precisely defined localities. In all cases but two, these early records could be ignored without affecting the comparisons we made. The beetle, *Lissotes latidens*, was first collected on Maria Island, off Tasmania's east coast, but had not been seen there for *c.* 30 years prior to SSS for the species in 1997 and 1998. In this case, we have arbitrarily assigned an OKSA of 1 $km^2$ to *L. latidens* on Maria Island prior to the SSS. In the case of the crayfish, *Astacopsis gouldi*, whose distribution was well known but poorly documented until the late 1980s, the pre-SSS localities used are the best-defined sites in Tables 1 and 3 in Horwitz (1991*a*).

Minimum convex polygons were calculated in ArcView GIS using the AlaskaPak extension (available from Alaska Support Office, Natl Pk Service, USA). Where MCP boundaries extended past the Tasmanian coastline, the non-land portion of the MCP was subtracted. In cases where species were found in areas well separated by water (*Lissotes latidens*, *L. menalcas* and *Tasmaphena lamproides*) or unoccupied land (*Astacopsis gouldi*), MCPs were calculated separately for each area and added together.

We determined the OKSA and MCP for each species before the SSS, just after the SSS (or before and after each SSS, when more than one had been carried out) and for the set of locality records as known to 15 April 2001. In cases where localities from non-SSS surveys were recorded while SSS was in progress, the non-SSS records were treated as post-SSS. We also noted the number of unique localities so far recorded for each species, i.e. the number of localities with unique UTM values. There are undoubtedly instances among the 1236 records we accepted where different UTM values apply to the same site, perhaps because a map was misread or because a recent locality nests within an older, less precise one. We are confident that such confusions do not significantly affect either the OKSA or MCP results.

We also compiled answers to the following questions:

- Why was SSS carried out?
- How much search effort (persons × field days) was involved in SSS?
- How was SSS funded?
- What was the 'by-catch' in records for non-target species?

Our principal sources of information on SSS were the publications and unpublished reports cited in Table 3, the database of threatened fauna localities maintained by the Forest Practices Board, Tasmania,

**Table 2. Changes in distribution measures with single-species sampling (SSS)**

OKSA = no. 1-km Universal Transverse Mercator (UTM) grid squares with records; MCP = area of minimum convex polygon in sq. km. (less offshore area; see Methods); localities = number of unique sites, typically 100-m UTM grid squares. Species abbreviations: (land snails) Anla = *Anoglypta launcestonensis*, Heru = *Helicarion rubicundus*, Miwe = *Miselaoma weldii*, Tala = *Tasmaphena lamproides*; (velvet worms) Oocr = *Ooperipatellus cryptus*, Taan = *Tasmanipatus anophthalmus*, Taba = *Tasmanipatus barretti*; (crayfish) Asgo = *Astacopsis gouldi*, Enor = *Engaeus orramakunna*, Ensp = *Engaeus spinicaudatus*, Enya = *Engaeus yabbimunna*; (millipede) Lial = *Lissodesmus alisonae*; (lucanid beetles) Hobo = *Hoplogonus bornemisszai*, Hosi = *Hoplogonus simsoni*, Lila = *Lissotes latidens*, Lime = *Lissotes menalcas*.

| | | Anla | Heru | Miwe | Tala | Oocr | Taan | Taba | Asgo | Enor | Ensp | Enya | Lial | Hobo | Hosi | Lila | Lime |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before 1st SSS | OKSA | 53 | 5 | 1 | 6 | 6 | 2 | 1 | 55 | 5 | 1 | 1 | 8 | 7 | 13 | 6 | 13 |
| | MCP | 1860 | <1 | na | 272 | 128 | na | na | 7090 | 37 | na | na | 1551 | 2 | 132 | 98 | 1247 |
| | Localities | 60 | 5 | 1 | 7 | 6 | 3 | 2 | 55 | 5 | 1 | 1 | 9 | 4 | 8 | 9 | 13 |
| After 1st SSS | OKSA | 93 | 11 | 3 | 24 | 12 | 13 | 32 | 75 | 54 | 13 | 3 | 92 | 11 | 16 | 25 | 28 |
| | MCP | 2218 | 52 | <1 | 418 | 849 | 198 | 469 | 8533 | 282 | 21 | 4 | 4965 | 7 | 163 | 276 | 1259 |
| | Localities | 109 | 23 | 9 | 29 | 12 | 15 | 33 | 79 | 83 | 18 | 3 | 93 | 21 | 16 | 32 | 28 |
| Before 2nd SSS | OKSA | – | 23 | – | 30 | 14 | 17 | 34 | – | – | 13 | 3 | – | – | 16 | 25 | 28 |
| | MCP | – | 53 | – | 718 | 1212 | 205 | 480 | – | – | 21 | 4 | – | – | 163 | 276 | 1259 |
| | Localities | – | 34 | – | 38 | 13 | 21 | 35 | – | – | 18 | 3 | – | – | 16 | 32 | 28 |
| After 2nd SSS | OKSA | – | 35 | – | 38 | 25 | 27 | 47 | – | – | 17 | 9 | – | – | 35 | 25 | 33 |
| | MCP | – | 65 | – | 760 | 1301 | 227 | 790 | – | – | 29 | 8 | – | – | 236 | 276 | 1555 |
| | Localities | – | 75 | – | 46 | 27 | 32 | 48 | – | – | 42 | 11 | – | – | 51 | 32 | 34 |
| Before 3rd SSS | OKSA | – | – | – | 44 | – | 36 | – | – | – | – | 11 | – | – | 36 | – | – |
| | MCP | – | – | – | 761 | – | 232 | – | – | – | – | 43 | – | – | 236 | – | – |
| | Localities | – | – | – | 56 | – | 47 | – | – | – | – | 16 | – | – | 53 | – | – |
| After 3rd SSS | OKSA | – | – | – | 49 | – | 40 | – | – | – | – | 27 | – | – | 59 | – | – |
| | MCP | – | – | – | 1090 | – | 232 | – | – | – | – | 125 | – | – | 241 | – | – |
| | Localities | – | – | – | 61 | – | 51 | – | – | – | – | 36 | – | – | 108 | – | – |
| Before 4th SSS | OKSA | – | – | – | – | – | – | – | – | – | – | – | – | – | 63 | – | – |
| | MCP | – | – | – | – | – | – | – | – | – | – | – | – | – | 253 | – | – |
| | Localities | – | – | – | – | – | – | – | – | – | – | – | – | – | 118 | – | – |
| After 4th SSS | OKSA | – | – | – | – | – | – | – | – | – | – | – | – | – | 68 | – | – |
| | MCP | – | – | – | – | – | – | – | – | – | – | – | – | – | 253 | – | – |
| | Localities | – | – | – | – | – | – | – | – | – | – | – | – | – | 127 | – | – |
| As of 15 April 2001 | OKSA | 114 | 36 | 3 | 50 | 46 | 42 | 98 | 133 | 59 | 18 | 28 | 164 | 12 | 68 | 27 | 33 |
| | MCP | 2359 | 65 | <1 | 1090 | 2768 | 232 | 907 | 9203 | 352 | 29 | 137 | 6154 | 10 | 253 | 279 | 1555 |
| | Localities | 129 | 77 | 9 | 62 | 54 | 55 | 126 | 151 | 97 | 43 | 38 | 177 | 23 | 127 | 34 | 35 |

and our own records. Included in the References section are all unpublished reports cited in this paper. The data in Table 2 include a few non-SSS locality records taken from uncited reports and publications.

## Results

All species surveyed, except the millipede, *Lissodesmus alisonae*, are either currently listed under the *Threatened Species Protection Act 1995* (Tasmania) or were listed at the time SSS was first conducted (Table 1). The distribution of *L. alisonae* was intensively mapped for biogeographical purposes. The other 15 species were surveyed by SSS because existing distribution information indicated that the species range was unusually small, fragmented or shrinking, and because additional distribution and habitat information was thought to be 'vital for the formulation of any conservation management initiatives required to ensure [the species'] security' (Meggs 1999*a*). In three of the four searches for lucanid beetles, the principal aim was to test the predictive power of a habitat model.

The individual SSS results, whether expressed as OKSAs, MCPs or number of localities, were highly variable functions of search effort. As a group, the 29 SSS projects added 667 new localities (Table 2) after *c.* 870 person-days in the field (Table 3), or only one new locality every 1.3 person-days. The success rate was low, in part, because not all the field time was spent in deliberate searches, some time was spent in confirming previously known localities and some search sites were in remote locations. Perhaps more importantly, most of the 16 targeted invertebrates were rare, highly cryptic or both. The velvet worm, *Ooperipatellus cryptus*, for example, often shelters deep in rotting logs. During SSS 1 for this species (Table 3), specimens were found at only seven of 38 apparently suitable sites now known to be within the *O. cryptus* range. In contrast, the burrows of *Engaeus* crayfish may be relatively easy to find, but their occupants are not; burrow systems can be extensive and highly convoluted, and single specimens may take from minutes to hours to capture. Flooding of waterways, burrows or soil also made some sampling for *Engaeus* highly weather dependent.

**Table 3. Notes on single-species sampling (SSS) projects**

Effort = (no. field days) × (no. searchers); funding = principal source of field expenses. Species abbreviations as in Table 2. The Tasmanian 'Forestry Commission' was re-named 'Forestry Tasmania' in the early 1990s. TSU =Threatened Species Unit, currently within the Tasmanian Department of Primary Industry, Water and Environment. NFP-Triabunna = Triabunna division of North Forest Products, now a division of Gunns Ltd. F = Commonwealth program or agency, S= State agency, P = private funding source.

| Species | SSS | Dates | Effort | Funding | By-catch | References |
|---|---|---|---|---|---|---|
| Anla | 1 | Jan–Feb 1996 | 53 | Forestry Tasmania (S) | Land snails | Bonham (1996*a*, 1996*b*) |
| Heru | 1 | Jul, Dec 1989 | 5 | Forestry Commission (S) | Land snails | Taylor (1991) |
| | 2 | Apr–Jun 1999 | 20 | Forestry Tasmania (S) | None | Otley *et al.* (1999) |
| Miwe | 1 | May 1998 | 6 | TSU (S) | Land snails | Bonham (1999*a*) |
| Tala | 1 | Sep 1992 | 18 | Forestry Commission (S) | Land snails | Bonham (1992, 1997), Bonham and Taylor (1997) |
| | 2 | Jul 1999 | 8 | Forestry Tasmania (S) | Land snails, Oocr | Bonham (1999*b*) |
| | 3 | Sep 2000 | 5 | TSU (S) | Land snails | Bonham (2000) |
| Oocr | 1 | Nov 1991 | 14 | National Rainforest Conservation Program (F) | Velvet worms, millipedes | Mesibov (1991) |
| | 2 | Oct, Dec 1992 | 13 | Forestry Commission (S) | Velvet worms, Tala | Mesibov (1993) |
| Taan | 1 | Aug–Sep 1987 | 36 | Plomley Foundation (P) | None | Mesibov (1987) |
| and Taba | 2 | Nov 1988 | 12 | National Estate Grants Program (F) | Velvet worms | Mesibov (1988), Mesibov and Ruhberg (1991) |
| Taan | 3 | Mar–Apr 1997 | 6 | TSU (S) | Taba | Mesibov (1997) |
| Asgo | 1 | 1990, 1991 | 28 | National Estate Grants Program (F) | Crayfish | Horwitz (1991*a*), Horwitz (1994*b*) |
| Enor | 1 | Jun–Nov 1996 | 85 | Australian Nature Conservation Agency (F), Forestry Tasmania (S) | Crayfish, other invertebrates | Doran and Richards (1996) |
| Ensp | 1 | Sep 1990–Jan 1991 | 36 | Endangered Species Program (F) | Crustaceans, other invertebrates | Horwitz (1991*b*) |
| | 2 | Sep 1997 | 6 | Forest Practices Board (S), Parks and Wildlife Service (S) | None | Richards (1997) |
| Enya | 1 | Dec 1992 | 2 | Self funded by collector (P) | Crayfish | Horwitz (1994*a*) |
| | 2 | Jul 1996 | 13 | Australian Nature Conservation Agency (F), Forestry Tasmania (S) | Crayfish | Doran and Richards (1996) |
| | 3 | Aug-Sep 1998 | 12 | Private Land Reserve Program (F) | Crayfish | Doran (1998) |
| Lial | 1 | Feb 1992–Aug 1994 | *c.* 50 | Plomley Foundation (P) | Millipedes, centipedes, velvet worms | Mesibov (1994) |
| Hobo | 1 | Jan–Feb 1999 | *c.* 20 | Forest Practices Board (S) | Hosi, Taba | Richards (1999) |
| Hosi | 1 | Nov 1995–Mar 1996 | *c.* 35 | National Estate Grants Program (F), Forestry Tasmania (S) | Other litter invertebrates | Meggs (1996*a*) |
| | 2 | Nov 1996–May 1997 | *c.* 150 | W. V. Scott Foundation (P), Forest Practices Board (S), Forestry Tasmania (S) | Hobo | Meggs (1997) |
| | 3 | Mar–Jul 1998 | *c.* 80 | Forest Practices Board (S), Forestry Tasmania (S) | None | Meggs (1998) |
| | 4 | Jan–Feb 2000 | *c.* 20 | Forest Practices Board (S), Forestry Tasmania (S) | None | J. M. Meggs, S. Munks and K. Richards (unpublished results) |
| Lila | 1 | Nov 1997–Feb 1998 | *c.* 90 | Forest Practices Board (S), Forestry Tasmania (S), NFP-Triabunna (P) | None | Meggs (1999*a*) |
| | 2 | May 1998 | *c.* 10 | Forestry Tasmania (S) | None | Meggs (1999*b*) |
| Lime | 1 | Nov 1995–Mar 1996 | *c.* 35 | National Estate Grants Program (F), Forestry Tasmania (S) | Other litter invertebrates | Meggs (1996*a*) |
| | 2 | Jun 1998 | 8 | Forestry Tasmania (S) | None | Meggs and Taylor (1999) |

Since the first SSS was carried out in each case, another 381 locality records for the 16 species were added through casual collecting or SSS for other species (Table 2). Listing of threatened species (and SSS for those species) has made Tasmanian field workers more aware of the listed species and of the desirability of noting additional localities. The 1048 new records (667 + 381) in the SSS period of increased awareness represent 85% of all known records for the 16 species.

All but one of the 29 SSS projects increased the number of OKSAs from which the target species was known (Table 2). The exception was the second SSS for the lucanid beetle, *Lissotes latidens*, which was predicted by a habitat model to occur on Tasman and Forestier Peninsulas in south-eastern Tasmania, but which was not found there in *c.* 10 days of fieldwork (Table 3). This SSS and another two searches (*Tasmanipatus anophthalmus* SSS 3 and *Hoplogonus simsoni* SSS 4) also failed to increase the MCP of the target species (Table 2). In these cases, the SSS aimed to validate the presumed area of occupation within the provisionally known range boundary. In most of the other surveys, the area searched for the target species grew at the edges of an already known distribution, the aim being to locate the true limits of the current range.

Currently, the ranges of all 16 species are believed to be reasonably well known as a result of SSS. This confidence is based on 9–177 localities (*c.* 20-fold range) and OKSAs of 3 to 64 km$^2$ (*c.* 20-fold range) for species with range sizes of <1 km$^2$ to 9203 km$^2$ (*c.* 10,000-fold range). It is interesting that the spreads of localities and OKSAs are so much smaller than the spread of ranges. Even excluding the highly restricted *Miselaoma weldii* and *Hoplogonus bornemisszai* and the relatively widespread *Astacopsis gouldi* and *Lissodesmus alisonae*, the spreads of distribution measures are disproportionate: localities, 34–129 (*c.* 4-fold); OKSAs, 18–114 km$^2$ (*c.* 6-fold); and range size 29–2768 km$^2$ (*c.* 90-fold). The 16 ranges are thus 'well known' mainly as geographical envelopes; the internal range structure of the more restricted species is considerably better documented than that of the more widely distributed ones.

Searches were funded from Commonwealth, State and private sources (Table 3), and joint Commonwealth/State and State/private initiatives supported roughly half the total field effort. Although it appears in Table 3 that the single largest supporter of fieldwork was the state forestry agency, Forestry Tasmania (formerly Forestry Commission) support for several of the more recent SSS projects came through Forestry Tasmania from a Commonwealth fund established under the 1997 Regional Forest Agreement.

No localities for non-target species seem to have been recorded in eight of the 29 SSS projects (Table 3). In the remainder, the by-catch was largely or entirely limited to species in the same taxonomic group.

## Discussion

Because habitat information was generally also recorded during SSS, both at successful and unsuccessful search sites, SSS has assisted in the recognition of suitable and unsuitable habitat for individual species. Autecological data of this kind have been used in predictive range modelling for the beetles, *Hoplogonus simsoni* (Meggs 1997), *Lissotes latidens* (J. Meggs and S. Munks, unpublished results) and *Lissotes menalcas* (Meggs and Taylor 1999), and in non-quantitative descriptions of suitable habitat for most of the other 13 species. Armed with habitat descriptions, conservation planners have in some cases carried out GIS-based assessments of the total extent of habitat and, critically, the extent of reserved habitat available within the range of the species concerned.

Distribution data from SSS have also been applied to biogeographical studies, notably for snails (K. J. Bonham, work in progress). Without fine-scale mapping, the remarkably tight parapatry exhibited by the species pairs, *Tasmanipatus anophthalmus*/*T. barretti* (Mesibov and Ruhberg 1991), *Lissodesmus alisonae*/*L. adrianae* (Mesibov 1997) and *Hoplogonus simsoni*/*H. bornemisszai* (Richards 1999) would not have been apparent. Similarly, the previously recognised and very distinct parapatry of *Engaeus* species, particularly in the north-east of the state (Horwitz 1990, 1996), has been resolved in greater detail through SSS (Doran and Richards 1996).

In a legal sense, the principal conservation outcome of SSS has been listing (or de-listing) of the 15 non-millipede species in Table 1 in the schedules of the Tasmanian *Threatened Species Protection Act 1995*. In some cases, SSS was first carried out after listing and has helped to validate the conservation judgment made when the species was listed. The snail, *Anoglypta launcestonensis* was de-listed in 2000 largely as a result of SSS (Bonham 1996*a*), and SSS has led to recommendations for downgrading of listing status from 'vulnerable' to 'rare' for *Lissotes menalcas* (Meggs and Taylor 1999) and upgrading from 'vulnerable' to 'endangered' for *Miselaoma weldii* (Bonham 1999*a*) and *Engaeus spinicaudatus* (Horwitz 1991*b*; Richards 1997).

Listing has had the beneficial effects of highlighting invertebrate diversity, assisting forest management and stimulating research (Taylor and Bryant 1997), and locality data for listed species have been published (Bryant and Jackson 1999). However, conservation actions taken under the 1995 Act have been few. The crayfish, *Astacopsis gouldi*, is listed as a threatened species in both the Tasmanian Act and the Commonwealth *Endangered Species Act 1992*, but when recreational fishing of the species was banned in December 1997, the protection order was issued by the State Fisheries Minister acting under the *Inland Fisheries Act 1995*.

Protection for forest-dependent listed species in Tasmania is mainly being achieved through the *Forest Practices Act 1985*, which regulates forestry operations on both public and private land. The link between this Act and the *Threatened Species Protection Act 1995* lies in the requirement for planners of forest operations to take account of special values in the operational area, and among those special values are localities and habitats for listed fauna. In administering the *Forest Practices Act*, the Forest Practices Board (FPB) regularly seeks specialist advice on invertebrate conservation and maintains a continuously updated database of localities and potential habitat for listed invertebrates and for 'priority species' identified in the Tasmanian Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997). The most frequent users of locality data are professional forest planners, who are provided with the up-to-date records maintained by the FPB. In far north-western Tasmania, for example, the operational plans for an area of potentially suitable forest habitat within the known range of the snail, *Tasmaphena lamproides*, must include FPB-recommended prescriptions designed to minimise harm to local populations, and pre-operational surveys may be carried out within the area to locate high-quality *T. lamproides* habitat. If specimens are found, the new localities are added to the FPB database. The operational plan containing the conservation recommendations for *T. lamproides* and the results of any pre-operational survey is a legal document, and forestry operations cannot proceed on either public or private land in Tasmania without an approved plan of this kind.

Thus the principal end use of SSS results to date has been in the management of particular forest areas and habitats, not species. Forest managers are obliged to avoid further threatening listed species and their habitats, and SSS has been a key source of information on whether listed species are present in the areas being managed. Knowing that particular threatened species are present in an area, land managers have acted on specialist advice to align management practices for that area with the conservation needs of the species.

There are two major deficiencies in this approach to invertebrate conservation. First, if SSS has shown that an area is outside the well-known range of a listed species, then the conservation recommendations for that species need not be applied. That area, however, may contain the core of the small range of an as-yet-unstudied invertebrate with conservation requirements similar to those of the listed species. Given that short-range endemism appears to be common in the Tasmanian invertebrate fauna, this possibility seems likely. Second, it may be that managing an area for a particular listed species will have the unintended effect of threatening a short-range invertebrate resident in the same area whose distribution and ecology are inadequately known (or unknown).

Conservation recommendations for a listed species will, of course, also assist conservation of those invertebrates that are ecologically similar to that species and living within its range, and it may be that there are many such invertebrates. For example, habitat studies of 'log fauna' such as velvet worms and lucanid beetles in Tasmania have emphasised the need for retention of coarse woody debris in forestry operations (Meggs 1996*b*), as it is important habitat for a wide range of saproxylic species. However, coarse woody debris retention is a blanket prescription. Is fine-scale mapping of particular species of 'log fauna' of any use when coarse woody debris retention is recommended for all forests?

In using limited resources to target individual species, SSS is likely to fail to alert land managers of the existence and conservation requirements of short-range invertebrates other than the target species. As shown in Table 3, the invertebrate by-catch in SSS has so far been very limited. (A remarkable exception is the case of *H. simsoni* mapping (Meggs 1997), when two new, even more geographically restricted *Hoplogonus* species were discovered on the fringe of the *H. simsoni* range (Bartolozzi 1996*a*, 1996*b*)). It can thus be argued that SSS has not provided land managers with enough information. After considerable expense of field time and effort, SSS has told managers where particular species of conservation importance are living. It has not placed individual land areas, which are the focus of management efforts, in a realistic ecological context: as home to thousands of other invertebrate species about whose distributions and conservation requirements very little is known. It is remarkable that the total number of known localities for 'well-mapped' invertebrates varies so much less than the range sizes of those species (Table 2). Single-species sampling clearly involves a trade-off of field effort for information gained, and a species range can evidently be well enough defined by fewer than 200 locality records. A much larger number of records would be needed to provide an adequate picture of the invertebrate fauna of several square kilometres of forest or other habitat, and the number needed would increase in rough proportion to the size of the area being managed.

Although useful information has undoubtedly been gained from SSS, we see fine-scale mapping of geographically restricted invertebrates in Tasmania over the past decade as an extension of a species-by-species conservation methodology that is more suited to large or conspicuous animals in relatively low-diversity taxa. If the conservation aim of fieldwork is to gather distribution and habitat information of immediate use to managers of all the State's land, and of long-term benefit to the largest number of invertebrates, then SSS is not an efficient use of field time and resources.

We recommend instead that the highest priority for funding of conservation-oriented fieldwork should be for intensive sampling of functional groups most obviously at risk in targeted areas. In forests and woodlands subject to fuel-reduction burning, for example, the targeted groups would be in leaf and twig litter. In native forest to be converted to plantation, the targeted groups should include stream fauna, which are likely to be affected by siltation from road construction and clearing, and by stream warming following disturbance-induced death of streamside trees. Pre-plantation surveys should also target native earthworms, which have been shown to have very restricted distributions in Tasmania (Kingston 2000) and which are sensitive to soil disturbance and threatened by introduced earthworms carried by the machinery used in preparing plantation sites. Sampling needs to be intensive enough to capture locally uncommon taxa, and it must be documented well enough to support future reconsideration of the invertebrate values of the sampled area when the 'unidentifieds' in the collection are better understood.

Increasing the number of taxa collected will greatly increase the number of invertebrate locality records acquired per field day, and hence our knowledge of the biogeographical significance of the target area for the highly regionalised Tasmanian fauna (Mesibov 1996). It might also improve efficiency in the use of resources for fieldwork. In at least two cases (SSS for *Ooperipatellus cryptus* and *Tasmaphena lamproides* in north-western Tasmania, and for *Tasmanipatus barretti* and *Hoplogonus* species in north-eastern Tasmania), different workers searched much the same area and microhabitats in separate field efforts.

Conservation-oriented fieldwork should be carried out in those places where land managers need specialist advice most urgently. It is still relatively easy in Tasmania to obtain financial support for invertebrate sampling in national parks and wild areas, either to establish 'baselines' for long-term environmental monitoring or to help complete biological inventories of these special and well-conserved places. It is clearly just as important (some would argue more important) to provide foresters, farmers and wildland managers with advice on how and where invertebrates will be affected by forestry operations, clearing, burning and grazing. These demands should determine where sampling occurs. The highest priority areas for sampling should be those where logging, clearing, burning and grazing are about to happen for the first time, or are about to be intensified, or where remnants of native habitat are being lost. A second priority can be overlaid on the first: places with poorly known invertebrate faunas should be intensively sampled before places with better-known invertebrate faunas.

Functional group sampling in poorly known areas currently at risk would be a hybrid of the group- and area-focused sampling referred to in the Introduction. Like SSS, it would generate fine-scale habitat information and the raw material for biogeographical studies. We believe, however, that it would provide a substantially greater conservation benefit for each hour spent in the field. Table 3 shows that forest managers in Tasmania have been willing to fund SSS projects aimed at improving conservation of particular invertebrates in production forests. We are optimistic that funding would also be available for fieldwork more closely directed to the needs of forest management and more realistically inclusive of forest invertebrates.

It is unfortunate that, to date, managers of non-forest land in Tasmania have not followed the lead of forest managers in sponsoring fieldwork and acting on its results. The broader sampling we recommend would provide farm and urban land managers with faunal information on which to base conservation-oriented management actions, and might encourage greater acceptance of responsibility for the outcomes of land management decisions.

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