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Multiple measures are necessary to assess rarity in macro-molluscs: a case study from southeastern Australia

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Running heading: Rarity in intertidal molluscs.

Multiple measures are necessary to assess rarity in macro-molluscs: a case study from southeastern Australia

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20 **Abstract**

21 Our knowledge of suitable criteria to determine rarity in most marine
22 invertebrates is lacking, thus hindering targeted impact studies, long-term
23 monitoring programs, and associated conservation strategies. Standardized
24 definitions of rarity are required to enable comparisons of different
25 assemblages and taxa. Gaston (1994) has recommended that rare species
26 are defined as the lowest quartile of species in the assemblage. In this study,
27 the 25% 'cut-off' was applied to intertidal macro-molluscs along the Illawarra
28 Coast, Australia from 200 surveys of 13 reefs, using three measures of
29 population structure; 1) local abundance (numerical rarity); 2) number of
30 locations (spatial rarity) and; 3) percent of surveys (temporal rarity). Rare
31 species were consequently defined as those species with no more than; 1) a
32 local abundance of two individuals; 2) a regional occurrence at two reefs
33 and/or; 3) a temporal occurrence in 2% of all surveys. These cut-off values
34 increased when only intertidal specialists were analysed. Using a
35 combination of all three measures, 62 species (42%) were classified as
36 regionally rare, but only four of these were true intertidal specialists. Most
37 species were rare by only one or two definitions of rarity; illustrating the
38 importance of considering multiple measures of rarity and the need to design
39 specifically targeted survey methods for future monitoring. Many species that
40 are rare by all three definitions are likely to be temporary immigrants, as
41 subtidal species were significantly more likely to be classified as rare. Clearly
42 many factors can influence the rarity of marine invertebrates on intertidal

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43 reefs, and these must all be considered to set appropriate conservation
44 priorities.

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46 **Key words:** Definitions of rarity, endemism, rocky intertidal, marine
47 conservation, Mollusca, marine invertebrate.

48

49 **Introduction**

50 The protection of rare species is the central objective of many
51 conservationists. Unfortunately, we currently have little understanding about
52 measures of rarity that are appropriate for marine invertebrates, particularly
53 quantitative data on abundances, distributions, habitat requirements and
54 dispersal (Chapman 1999; but see Bouchet et al. 2002). Rare species are
55 usually regarded as those that appear to persist with naturally low
56 abundances and/or restricted geographic ranges (Rabinowitz et al. 1986;
57 Terborgh and Winter 1990; Gaston 1994; Chapman 1999; Gladstone 2002).
58 Rarity is often associated with vulnerability and extinction risk (Fagan et al.
59 2005; O’Hara 2002), although this depends on the underlying cause of rarity.
60 Marine invertebrate rarity can be due to natural processes, such as specific
61 habitat requirements (Angel et al. 2006), or competition (Barnes 2005); and it
62 may also be caused by anthropogenic activity such as climate change or
63 invasive species (Rogers-Bennett 2007).

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65 Assessments of rarity in marine invertebrates are crucial to conservation
management, as they are the first steps towards determining which species

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67 and ecological communities warrant action. Marine invertebrates are often
68 sessile, sedentary or slow moving, thus are unable to easily escape
69 stressors associated with agricultural run-off, pollution, harvesting or climate
70 change. Rocky shore animals may be particularly vulnerable to local and
71 global change, as many species already live at their physiological limits
72 (Helmuth et al. 2006; Hutchings et al. 2007). However, in most marine
73 bioregions there is a paucity of useful historical data to identify species and
74 communities that are at risk, based on changes in their patterns of rarity.
75 Baseline surveys for future long-term monitoring programs must account for
76 the natural temporal and spatial variation in species abundances. An
77 understanding of how different aspects of population structure influence
78 rarity in intertidal communities will facilitate the development of targeted
79 survey methodology for different types of rare species. Impact studies
80 examining effects of anthropogenic and natural changes in environmental
81 conditions could then target species that may be particularly vulnerable to
82 abiotic or biotic stressors due to their low abundances over time and space.
83 Systematic classification of rarity in marine invertebrates will also enable
84 assessment of any changes in the proportion of rare species found on rocky
85 reefs during monitoring programs.

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87 There are several viewpoints on the most appropriate way to quantify rarity
88 (reviewed by Soulé 1986; Gaston 1994). Marine invertebrate assemblages
89 typically exhibit a high degree of spatial and temporal variability (e.g.

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90 Underwood and Chapman 1998), and several measures of rarity may
91 therefore be necessary to rigorously assess marine invertebrate abundance
92 patterns (e.g. Shin and Ellingsen 2004; Benkendorff 2005). The most
93 commonly used criteria are based on relative abundance (e.g. McGowan
94 and Walker 1979; Maurer *et al.* 1999), the frequency of sightings (e.g.
95 Laurance 1991), and the number of localities from which species are
96 recorded (e.g. Schlacher *et al.* 1998; Gladstone 2002). Species are generally
97 regarded as rare if they are restricted to a few specialized sites (Hubbell and
98 Foster 1986). In many cases, rarity appears to be assigned as an intuitive
99 concept (Usher 1986; Gaston 1994; e.g. Shin and Ellingsen 2004,
100 Benkendorff 2005), with no rationale explaining the classification of species
101 as rare, uncommon or common. Consequently, Gaston (1994) suggests a
102 pragmatic approach, whereby rare species are defined as the lowest quartile
103 of species in a frequency distribution of the measured variable. Using a
104 standardized definition for different rarity categories based on quartiles, it
105 should be possible to establish differences in the cut-off points for rare
106 species within and across communities over time. Furthermore, shifts into
107 different rarity categories can indicate either the recovery or decline of a
108 particular species.

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110 Assessment of rarity in marine invertebrates also involves considerations
111 regarding spatial scale and geographic distribution. A cautious approach to
112 marine conservation should include the protection of regionally rare species,

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113 at least until we have a greater understanding of the genetic structure of
114 populations on larger geographic scales. At larger scales, species that are
115 endemic to an area will tend to have smaller distributions, and thus rarity can
116 become closely allied to endemism (Gaston 1994). However, endemic
117 species may be more locally abundant than many of the other species found
118 in the area, and therefore endemism does not necessarily imply rarity
119 (Gaston 1994). Although recent years have seen a surge in biodiversity and
120 vulnerability studies of marine invertebrates (e.g. Bouchet et al. 2002;
121 Gladstone 2002; O'Hara 2002; Smith 2005), there is still little data available
122 for most marine invertebrates to assess rarity of species with broad or
123 narrow geographic ranges (Chapman 1999, Hutchings et al. 2007).

124

125 The assessment of species rarity could also be influenced by species
126 mobility (Davidson et al. 2004). A species that has recently immigrated from
127 population centers outside the study area will typically be classified as rare
128 (Hubbell and Foster 1986), primarily because it occurs at low abundances.

129 The influence of mobility on rarity assessments has particular relevance to
130 intertidal surveys, as some species may migrate between intertidal and
131 subtidal habitats. Similarly, visibility can affect the assessment of species
132 rarity, as populations of cryptic species are often overlooked and therefore
133 underestimated (Bouchet et al. 2002).

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135 Molluscs represent ideal models to compare rarity measurements of marine
136 invertebrates. Considerably more is known about marine molluscs than most
137 other invertebrate phyla, and molluscs have been shown to be an
138 appropriate indicator group for local invertebrate biodiversity (Gladstone
139 2002; Smith 2005). In addition, they are numerous, relatively slow moving
140 and easily identifiable (Connell 1972; Underwood 1998). Indeed, arbitrary
141 species abundance rankings have even been provided for some Australian
142 molluscs by several previous researchers (Wilson 1993; Jansen 2000; Edgar
143 1997; Lamprell and Whitehead 1992; Lamprell and Healy 1998; Marshall
144 and Willan 1999).

145

146 The aims of this study are; 1) to practically assess the rarity of molluscs on
147 intertidal reefs using an objective 25% 'cut-off'; and 2) to compare rarity
148 assignments from multiple measures of population structure with each other
149 and with intuitive definitions for species rarity. Gaston's lowest quartile
150 definition was applied to numerical, spatial, and temporal rarity, as well as a
151 combined measure of regional rarity, using three datasets: 1) a full dataset
152 including all species recorded on intertidal reefs, 2) a reduced dataset
153 excluding cryptic species and those observed to be more common in non-
154 intertidal habitats, and 3) an intertidal specialist dataset including species
155 restricted to the intertidal zone. The congruence between these measures
156 was also analyzed to determine the relative importance of including multiple
157 measures of rarity. Finally, rarity has been assessed at a larger geographic

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158 scale by examining the relationship between regional rarity and endemism.
159 This is the first study to systematically assess different measures of rarity
160 using Gaston's lower quartile criterion in marine invertebrates, and results
161 will be important on a practical regional level by identifying rare molluscan
162 species in south-eastern Australia. In addition, this study contributes more
163 broadly to methodology for future monitoring and conservation management,
164 providing guidelines for rarity assessments of marine invertebrates to
165 facilitate appropriate marine conservation strategies.

166

167 **Methods**

168 *Surveys*

169 Surveys of the macro-molluscan fauna (> ~ 5mm excluding juveniles) were
170 conducted on thirteen intertidal reefs along the Illawarra coast, N.S.W.
171 Australia (Figure 1). A total of 200 independent surveys were conducted
172 during periods of low tide (0.0-0.6m) from 1995-2000. Standardised one hour
173 timed search surveys were used in approximately 250m² areas spanning the
174 supralittoral to shallow subtidal zone (up to 1m below mean low tide) on
175 each reef. The entire range of habitats was investigated at all accessible
176 levels of the shore, including the tops and undersides of pebbles and
177 boulders, flat rock surfaces, caves and crevices, rock pools and artificial
178 swimming pools. The number of surveys varied at each site (see Figure 1)
179 according to accessibility due to wave exposure. The surveys were primarily
180 conducted during spring and summer when the tides were less than 0.3m,

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181 although some surveys were also undertaken at each site in other seasons.
182 At least four sites were sampled during each week of low tides and the order
183 of surveys was randomly distributed between sites, with each sites
184 repeatedly surveyed in each year of the study. Species accumulation curves
185 flattened at all sites within this time frame, with the exception of the three
186 most diverse sites around Shellharbour and Bass Point (see Benkendorff
187 and Davis 2002).

188

189 *Species identification*

190 Species were identified *in situ* wherever possible, but unknown species were
191 photographed and/or collected for subsequent identification using a
192 dissecting microscope in the laboratory. Eogastropods, vetigastropods,
193 neritids, and caenogastropods were identified according to Wilson (1993)
194 and Jansen (2000), with assistance from the Australian Museum. Where
195 there are discrepancies in species names between these two publications,
196 the nomenclature of Wilson (1993) was used. Heterobranchs were identified
197 using the Australian Museum's Online Seaslug Forum (Rudman 2008).
198 Pulmonates, polyplacophorans and cephalopods were identified according to
199 Edgar (1997). Bivalves were identified using Lamprell and Whitehead (1992)
200 and Lamprell and Healy (1998). Higher taxonomic groupings have been
201 assigned according to the classification outlined in Beesley et al. (1998)
202 (Appendix 1). Species have been grouped according to class, with the
203 exception of gastropods, which have been divided into subclasses. The

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204 largest subclass, Orthogastropoda, has been further divided into
205 superorders.

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207 *Species distribution*

208 Tidal zone distribution was recorded where possible from available literature
209 (Wilson 1993; Jansen 2000; Edgar 1997; Lamprell and Whitehead 1992;
210 Lamprell and Healy 1998; Rudman 2008), and species have been assigned
211 to one of four categories; intertidal specialists, shallow subtidal, pelagic or
212 unknown, to indicate whether the species are likely to occupy significantly
213 more habitat than suggested by the regional distribution from intertidal
214 surveys. Consequently, species that occur in both the subtidal and intertidal
215 zones have been classified as subtidal.

216

217 The geographic distribution refers to the known world-wide range for each
218 species and was derived from available literature (Wilson 1993; Jansen
219 2000; Edgar 1997; Lamprell and Whitehead 1992; Lamprell and Healy 1998;
220 Rudman 2008). Species have been classified as endemic to Australia,
221 occurring in temperate waters, occurring in tropical waters or cosmopolitan
222 (world-wide). No attempt has been made to further classify endemic species
223 according to their range within Australia because there is insufficient
224 information available for most species.

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226 *Assessment of species rarity*

227 Three measures of rarity have been assessed in this study 1) numerical
228 rarity; 2) spatial rarity and 3) temporal rarity. Numerical rarity was assigned
229 according to the maximum local abundance recorded using *in situ* visual
230 counts during any one survey at any of the reefs. The number of individuals
231 per reef was recorded for all species occurring at abundances of less than
232 50. Those that were more numerous were split into three approximate
233 classes of 50-100, 101-500 and greater than 500. Spatial rarity was
234 determined according to the number of localities from which each species
235 was recorded during the entire survey period (Figure 1). Temporal rarity was
236 calculated as the percentage of all surveys in which each species was
237 sighted. The frequency histograms for numerical and temporal rarity
238 included increments of 1 at the lower end of the scale. Then species were
239 grouped as follows; 4-5, 6-10, increments of 10 up to 100; and, for numerical
240 rarity, 101-500 and >500 individuals (Figure 2).

241
242 A relative cut-off of 25% was applied using each of the three rarity measures
243 (Gaston 1994). Using the raw data, species were ranked in order of
244 abundance or frequency and those species falling in the first quartile (0-25%)
245 of the frequency distribution were classified as rare. Species in the second
246 quartile were considered uncommon, those in the third quartile were
247 regarded as common and those in the upper quartile were classified as
248 abundant. The proportion of species in each category does vary slightly from

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249 25% so that species with the same abundance rankings are assigned to the
250 same category.

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252 An overall classification of regional rarity was assigned using a combination
253 of the three rarity measures, such that those species classified as rare using
254 any one of the three measures were considered regionally rare. Similarly,
255 species falling into any one of the uncommon categories were classified as
256 regionally uncommon, with the exception of those already classified as rare.
257 Regionally common species were assigned in the same manner, with the
258 remaining species classified as abundant in the region. The lack of
259 independence between the three methods for assessing species rarity, as
260 detailed in the next section, indicates that it is not appropriate to rank
261 species as being more or less rare according to the number of measures in
262 which they are classified as being rare. An alternative would be to class only
263 those species that met all three criteria as rare, but we opted for a more
264 conservative approach regarding implications for conservation management.

265

266 Rarity was assessed for full, reduced and intertidal-only datasets; unless
267 explicitly stated in the text, all values and statements hereafter relate to the
268 full dataset. The reduced dataset includes only those species for which we
269 believe our records are representative based observations and literature
270 references and excludes species that were a) pelagic, b) observed more
271 commonly along the Illawarra Coast during dives in the shallow subtidal

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272 zone or reported as common in other habitats from the literature, c) more
273 commonly found in death assemblages washed up on adjacent shores than
274 in our intertidal surveys, and d) easily overlooked due to camouflage or
275 cryptic habitats (refer to Appendix 1).

276

277 *Statistical analysis*

278 Statistical analyses were performed using the JMP statistical package. A
279 Pearsons Chi-square test was used to test for heterogeneity in the likelihood
280 that species were assigned to the different rarity categories depending on
281 their tidal and geographic distribution. Due to the small numbers of species
282 in some categories, the species were grouped as either endemic or non-
283 endemic. All species whose distributions were uncertain (including those not
284 identified to species level) were excluded from these analyses (Appendix 1).
285 A Chi-square test was also used to determine the likelihood that species
286 were recorded in previous studies along the Illawarra Coast (Owen 1978;
287 Miskiewicz and Lock 1991; Marine Pollution Research 1992; 1995;
288 Minchinton 1996; Waters 1997), based on their regional rarity.

289

290 **Results**

291 In total, 146 species of molluscs were recorded in the intertidal zone along
292 the Illawarra Coast, NSW, Australia (Appendix 1). Only 19% of the species
293 recorded in this study are thought to be restricted purely to the rocky
294 intertidal zone, with 62% known to extend into shallow subtidal waters

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295 (Figure 2a; Appendix 1). The majority of species recorded appear to be
296 endemic to Australia (60%), with a further 12% only occurring in temperate
297 waters (Figure 2b), primarily only Australia and New Zealand (Appendix 1).
298 Only a small proportion of species recorded in this study are known to have
299 worldwide distributions (9%), although a further 13% occur throughout the
300 tropical Indo-West Pacific (Figure 2b). Five percent of species had unknown
301 geographic distributions.

302

303 *Single measures of rarity*

304 The 25% cut-off for numerically-rare species in the full dataset occurred at a
305 maximum of two individuals per reef (Figure 3a, see Table 1 for cut-off
306 values for other quartiles). Based on these cut-off values, 39 species (26.7
307 %) were classified as rare (Table 2, Appendix 1). The species abundance
308 distribution for these molluscs is skewed to the right, with a large number of
309 species only ever recorded as single individuals per reef (Figure 3a). Pooling
310 into larger abundance classes on the right side of the graph causes the
311 apparent bimodality of this frequency distribution.

312

313 The first quartile for spatial rarity in the full dataset included only those
314 species recorded at one or two sites (Table 1, Figure 3b). Based on this cut-
315 off value, 47 species (32.2%) have been classified as rare (Table 2,
316 Appendix 1). A large proportion of species were only observed on one reef,

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317 whereas another group of species were observed on every reef that was
318 surveyed, and the associated frequency distribution is bimodal (Figure 3b).

319
320 The cut-off value for temporal rarity in the full data set occurred within two
321 percent of all surveys (Table 1; Figure 3c), and 46 species (31.5%) were
322 classified as rare (Table 2, Appendix 1). The associated frequency
323 distribution again shows a bimodal distribution (Figure 3c). The distribution is
324 strongly skewed to the right, with 66% of the species being observed in less
325 than 10% of the surveys.

326
327 Rarity cut-offs in the reduced dataset were at higher values than the full
328 dataset for all three measures of rarity (Table 1). The frequency distribution
329 patterns for spatial, numerical and temporal rarity were similar to that of the
330 full dataset (Figure 3). In contrast to full and reduced datasets, application of
331 the 25% cut-off to the intertidal-only dataset revealed large shifts towards
332 the higher end of the rarity scales (Table 1). The frequency distributions for
333 numerical, spatial and temporal rarity were all heavily skewed towards the
334 left (Figure 3), due to the large proportion of intertidal species that were
335 found in large numbers (>100), at every reef in every survey (Appendix 1).
336 This resulted in a lack of discrimination between species in the common and
337 abundant categories (Table 1). This result may be influenced by the
338 relatively low number of species in the intertidal dataset (27).

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340 *Multiple measures of rarity*

341 Less than 47% of the species were classified in the same rarity categories
342 by all three measures (Table 2). The lowest overlap between the different
343 measures of rarity was observed when the data for numerical and spatial
344 rarity were compared. There was a direct correspondence in the
345 classification of only 52.1% of the species using these two measures (Table
346 2). By comparison, there was 67.8% correspondence between spatial and
347 temporal classifications. In general there was greater complementarity
348 between the methods in the rare and abundant categories, compared to
349 those species that were classified as uncommon or common (Table 2).
350 Nevertheless, a total of 20 species were only classified as rare by a single
351 measure of rarity (numerical: 9 species, spatial: 6 species, temporal: 5
352 species; Appendix 1).

353

354 Most of the differences in the classifications between methods involved
355 adjacent rarity categories. For example, species were recorded as rare using
356 one method and uncommon using another (Table 3). However, two species
357 were classified as rare using at least one method and abundant using
358 another (Table 3). One of these species (*Octopus tetricus*) was classified as
359 numerically rare but was observed on nearly every reef in the region and
360 was recorded in 50% of all surveys. On the other hand, *Stylocheilus*
361 *longicauda* was found to be numerically abundant, but temporally rare. A
362 further four numerically-rare species were classified as common based on

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363 the number of locations at which they were recorded (*Cymatium*
364 *parthenopeum*, *Oxynoe viridis*, *Doriopsilla carneola*, *Austraeolis ornata*).

365
366 Combining the three measures of rarity to produce an overall assessment of
367 regional rarity resulted in the majority of species (42.5%) being classified as
368 rare (Table 2). A further 22.6% of species were classified as uncommon,
369 with 19.9% classed as common and only 15.1% regarded as abundant in the
370 Illawarra region. Similar percentages were obtained in the other datasets,
371 with 36.8% and 32.1% of species being classed as rare in the reduced and
372 intertidal datasets respectively. Of the 62 species that were classified as rare
373 in the full dataset, 27 (43.5%) were classed as rare by all three measures of
374 rarity (Table 2). A further 22.6% of rare species were classed as rare by any
375 two measures, with the remaining 33.9% rare by only one of the three
376 definitions (Appendix 1).

377
378 *Impact of distribution on rarity assessment*

379 Subtidal species were more likely to be classified in the lower classes of
380 rarity, whereas intertidal species were more likely to be abundant (Figure
381 4a). A Chi-square test for heterogeneity confirmed a significant difference in
382 the proportions of subtidal and intertidal species that were classified in the
383 different rarity categories ($\chi^2 = 31.5$; $p < 0.001$). Of the 62 species recorded
384 as regionally rare, only four are known intertidal specialists (Appendix 1).

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386 The geographic distribution has been previously recorded for all species
387 classified as abundant in this study, but was unknown for several of the rare,
388 uncommon and common species (Appendix 1, Figure 4b). At least one rare
389 endemic is thought to be restricted to the N.S.W. coast, Australia (*Clanculus*
390 *clangus*, Appendix 1), although a much higher proportion of rare species
391 have a tropical or world wide distribution (Figure 4b). Only one tropical
392 species (*Nodilittorina pyramidalis*) and no cosmopolitan species were
393 classified as abundant (Figure 4b). Endemic species were significantly more
394 likely to be classified as abundant compared to non-endemics ($\chi^2 = 12.9$; $p =$
395 0.005).

396

397 **Discussion**

398 This study has shown that the use of quartile cut-offs provides a
399 standardized method to assess rarity in rocky shore invertebrates that is
400 generally consistent with intuitive definitions of rarity. Using the full data set,
401 a total of 62 species of molluscs were classified as rare on intertidal reefs in
402 southeastern Australia, with cut-off values similar to the ranges that have
403 been arbitrarily used in a number of previous studies on marine invertebrates
404 (e.g. Schlacher et al. 1998; Marshall and Willan 1999; Maurer et al. 1999;
405 O'Hara 2002; Benkendorff 2005). This suggests that Gaston's lower quartile
406 criterion, which was developed using data sets from terrestrial ecosystems
407 (Gaston 1994), can be applied to marine rocky shore communities.

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409 By applying the 25% cut-off criterion to comparable surveys in the future, it
410 will be possible to detect major changes in the community structure, as
411 indicated by shifts in the cut-off points for the different rarity categories. Any
412 decrease in the cut-off values will imply a major negative impact on the
413 community (as on average species are encountered less often); whereas
414 any increase in cut-off values could imply the community is in a state of
415 recovery, or possibly influenced by the establishment of a suite of invasive
416 species at the more abundant end of the scale. Somewhat unexpectedly,
417 application of the quartile cut-off criterion also resulted in deviations above or
418 below 25% of species in each rarity category due to the need to group
419 species with the same abundance or frequency in the same category. This is
420 advantageous for future monitoring programs because slight changes in the
421 proportion of species falling into each category can be detected even when
422 the cut-off values remain the same, thus indicating a shifting or unstable
423 community potentially vulnerable to future cumulative impacts. Such a
424 community could be targeted for regular monitoring, in order to establish if a
425 continual decline is occurring prior to a more dramatic change in cut-off
426 values.

427
428 Application of quartile cut-offs can also contribute towards understanding the
429 distribution of rare species within a particular assemblage. For each of the
430 three measures of population structure used in this study, frequency
431 distributions for all molluscs found on intertidal reefs in the Illawarra region

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432 are skewed to the right. This pattern is consistent with previous studies on a
433 wide range of communities, whereby most species are represented by low
434 numbers of individuals and most of the individuals belong to a few abundant
435 species (e.g. Fisher et al. 1943; MacArthur 1957). In contrast, the frequency
436 distribution for species abundance using exclusively intertidal species was
437 skewed to the left, indicating a large proportion of common or abundant
438 species are well adapted to intertidal reefs. The frequency distributions for
439 spatial and temporal occurrence of the intertidal dataset are bimodal,
440 indicating that there is one group of molluscs whose presence is entirely
441 predictable on intertidal reefs, while many other species are highly
442 unpredictable in space and time.

443
444 Multiple measures of population structure for rarity assessment are
445 advantageous because they encompass several variables that may
446 influence species dominance in an assemblage. In this study there was only
447 52-68% overlap in the classifications of species using three different
448 measures, suggesting that each of these is representing a different
449 component of rarity within the assemblage. Previous authors have
450 recognized as many as seven different forms of rarity in terrestrial
451 organisms, which incorporate aspects of population size, range and habitat
452 specificity (e.g. Rabinowitz et al. 1986; Yu and Dobson 2000). However,
453 these types of studies require significant knowledge of the species and their
454 niche requirements across a large geographic scale and are therefore

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455 difficult to apply to many marine invertebrates. Regardless of the measures
456 used in rarity assessments, spatial and temporal replication is crucial when
457 designing surveys for the conservation of marine invertebrates, because
458 regionally rare species are generally less likely to be detected. Only a small
459 proportion of the molluscs that were classed as rare in this study have been
460 previously recorded along the Illawarra Coast in snap shot surveys of
461 species richness for environmental management purposes (Owen 1978;
462 Miskiewicz and Lock 1991; Marine Pollution Research 1992; 1995;
463 Minchinton 1996; Waters 1997). Rarity significantly influenced the likelihood
464 that molluscs were included in previous species lists ($\chi^2 = 50.2$, $p < 0.001$). A
465 *priori* knowledge of the different types of rare species that occur within a
466 bioregion will enable targeted studies at particular sites of interest for future
467 environmental impact assessment.

468
469 Cryptic species habits and the interconnectedness of intertidal and subtidal
470 habitats create further problems for assessing the rarity of species on
471 intertidal reefs. The results from our reduced datasets suggest when those
472 species that can not be reliably assessed in the intertidal zone are excluded,
473 the cut-off values for rarity categories increase. In particular, mobility across
474 tidal zones must be considered in these rarity analyses, because most of the
475 species classified as rare by all three measures in our study are known to
476 inhabit the subtidal region. Such species are often termed incidentals,
477 vagrants, or immigrants (Gaston 1994) because they do not appear to

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478 maintain viable populations in the study area. From an ecological
479 perspective, immigrants should be regarded as a part of the community
480 because they could contribute to species interactions (Gaston 1994).
481 However, from a conservation perspective, rare immigrants should usually
482 be ignored because there are likely to be other areas that are more effective
483 for their conservation. Species that are both rare and restricted to intertidal
484 reefs should be considered of highest priority for intertidal conservation (e.g.
485 *Onchidella patelloides*). However, further studies are required on other rare
486 species to measure their abundance in subtidal habitats, specific habitat
487 requirements and other life history characteristics. The possibility that
488 intertidal reefs provide refuge or breeding habitat for some subtidal species
489 should not be overlooked (e.g. Rodgers et al. 1995; Benkendorff and Davis
490 2004).

491
492 The ability to detect the presence of rare species is particularly important for
493 the conservation and management of biological resources (Terborgh and
494 Winter 1980; Gaston 1994; van Jaarsveld et al. 1998), and the type of rarity
495 will help determine the appropriate conservation response. Species that are
496 rare in space or time may require a different form of conservation planning
497 compared to species with consistently low local abundances. Spatially-rare
498 species are potential habitat specialists restricted by the availability of
499 suitable sites (e.g. boulder fields, Chapman and Underwood 1996;
500 Benkendorff and Davis 2004). Habitat specialists are potentially vulnerable

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501 to stressors that negatively impact their habitat, such as recreational
502 activities like trampling and over-turning boulders, pollutants and agricultural
503 run-off. For these species, attempts should be made to identify and protect
504 those features of the environment that restrict them to specialized locations.
505 On the other-hand, temporally rare species could be migratory species or
506 species that spend extended periods of time as pelagic larvae (e.g. Kempf
507 1981). These species may therefore be more sensitive to changes in ocean
508 circulation and phytoplankton availability resulting from rising global
509 temperatures or off-shore activities. A better understanding of where these
510 species occur when not on intertidal reefs may be necessary for their
511 conservation.

512

513 The number of species treated as rare will vary greatly between studies, not
514 only due to lack of consistency in the application of standardized criteria to
515 assign rarity, but also due to the ranges and life histories of species included
516 in the datasets The majority of species recorded in this study appear to be
517 endemic to Australia (60%), compared to previous studies that have found
518 less than 10% endemism in molluscs from other parts of Australia (e.g.
519 Northern Australia, Wells 1990; Heron Island, Marshall and Willan 1999;
520 Victorian short range endemics, O'Hara 2002). A major focus for intertidal
521 molluscan conservation in Australia should perhaps be the few rare
522 endemics that are restricted to the intertidal zone (e.g. *Dolabrifera brazieri*
523 and *Hinea brasiliensis*). Additionally, several regionally-rare species have

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524 unknown geographic and/or tidal distributions and should also be priority
525 targets for future research (Appendix 1). Reproductive strategy and
526 differential recruitment may be other factors influencing molluscan
527 distributions and rarity on temperate Australian reefs. Broadcast spawners
528 and species with pelagic larvae are likely to have broader spatial
529 distributions than brooders or direct developers from benthic egg masses
530 (e.g. Scheltema 1989; Benkendorff and Davis 2004; Johnson et al. 2001).
531 Populations of direct developers may therefore be more sensitive to
532 temporary or stochastic change, such as pollutants, storms, or temperature
533 extremes, than populations of planktotrophs, which can more readily
534 recolonise areas after a disturbance via pelagic larval recruitment. However,
535 the regional rarity of species with dispersive larvae will depend on where the
536 source populations occur. In this study, a significantly higher proportion of
537 the regionally-abundant species are endemic, whereas the majority of rare
538 species have distributions extending beyond Australian waters. Endemic
539 species are expected to be self-replenishing, producing a large number of
540 recruits at a regional scale, whereas species with tropical and cosmopolitan
541 distributions may depend on the southern dispersal of pelagic larvae via the
542 East Australian Current. The East Australian Current has a seasonal cycle
543 with a strong southward flow of warm water during the austral summer
544 (Ridgway & Godfrey 1997) moving parallel to the Illawarra Coast, but with
545 anticyclonic (warm core) eddies (Tomczak and Godfrey 1994) providing
546 episodic pulses of warm water and potential recruits. This is consistent with

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547 the temporally and numerically rare occurrence of most tropical species in
548 this region.

549
550 The variation across rarity assessments due to biogeography and life
551 histories will be further influenced by both the inherent variation between
552 natural communities and the different sampling strategies used among
553 studies. Furthermore, the intensity of sampling in the study area (number of
554 sites) and the sampling effort (number of surveys) will clearly influence
555 appropriate cut-offs values for defining spatial and temporal rarity
556 respectively. However, the use of Gaston's quartile criterion to establish cut-
557 off points will help standardise the assignment of rare species, irrespective of
558 variations in sampling strategies. The defined cut-off points for rare species
559 within the same ecosystem and region could be compared for different
560 sampling designs to establish any predictable differences. This will then
561 enable direct comparison of the rarity assignment for particular species that
562 are common to different surveys; in order to detect any apparent changes
563 time and space. The inclusion of only those species that can be reliably
564 represented in marine surveys will also help facilitate direct comparisons
565 between assemblages.

566
567 Conservation strategies should not only account for multiple types of rarity,
568 but also incorporate measures of community assessment including species
569 richness, habitat specificity, reproductive strategies and endemism (Awad et

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570 al. 2002; Benkendorff and Davis 2002; Benkendorff and Davis 2004). In this
571 study, a large proportion of molluscs were found to be rare, but only one of
572 these species is currently protected from collection on intertidal reefs in
573 N.S.W., Australia; the numerically rare species, *Octopus tetricus* (N.S.W.
574 Fisheries Management Act, 1994). The lack of knowledge about life history,
575 ecology, biogeography and human impacts for most marine invertebrate
576 species likely hinders appropriate conservation strategies. Furthermore,
577 comprehensive studies on species rarity in different locations and
578 ecosystems will be labour intensive, requiring replicated quantitative
579 surveys, such as reported here. This is unlikely to be compatible with rapid
580 biodiversity assessment programs, such as those championed by
581 Conservation International (e.g. Willink et al. 2004). Nevertheless, rapid
582 “snap shot” surveys can be used to assess spatial distribution and
583 subjectively rank species according to their numerical abundance (e.g.
584 Benkendorff 2005). In this way, species in the lower quartile for numerical
585 and spatial rarity can be targeted for more in-depth studies. Once rare
586 species are identified, the underlying causes of rarity should be investigated
587 to determine the appropriate management strategy. Standardized
588 assessment of multiple measures for rarity across a range of habitats and
589 ecosystems will complement rapid biodiversity assessment for conservation
590 purposes and provide an important step towards suitable management of
591 potentially vulnerable species.

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767 **Appendix:** List of species found in this study, including rarity assessments. See text for definition of local abundance, %
768 of surveys, and number of sites. Regional rarity was assessed on full, reduced and intertidal-only datasets. A = Abundant;
769 C = Common; U = Uncommon; R = Rare.

Family	Species	Local abundance	% of surveys	No. sites	Regional Rarity			Tidal Zone	Geographic distribution	No. of previous studies
					Full	Reduced	Intertidal			
CLASS GASTROPODA; SUBCLASS EOGASTROPODA										
Order Patellogastropoda										
Patellidae	<i>Patella peronii</i>	>500	100	13	A	A	--	Subtidal ¹	NSW-WA	1
Patellidae	<i>Patella chapmani</i>	0-20	5	2	R	--	--	Subtidal	NSW-SA, Tas.	0
Patellidae	<i>Cellana tramoserica</i>	>500	100	13	A	A	A	Intertidal	Qld-SA	5
Acmaeidae	<i>Notoacmaea petterdi</i>	50-200	85	13	A	C	C	Intertidal	SE Aust	4
Acmaeidae	<i>Patelloida alticostata</i>	20-100	30	12	C	C	--	Subtidal	NSW-WA	3
Acmaeidae	<i>Patelloida cf. mufria</i>	1-20	50	11	C	--	--	Subtidal ¹	NSW-WA	1
SUBCLASS ORTHOGASTROPODA Superorder Vetigastropoda										
Haliotidae	<i>Haliotis rubra</i>	1-3	5	8	U	--	--	Subtidal ¹	NSW-SA	2
Haliotidae	<i>Haliotis coccoradiata</i>	1-3	3	3	U	--	--	Subtidal ¹	NSW-Vic	0
Fissurellidae	<i>Scutus antipodes</i>	1-30	75	12	C	C	--	Subtidal	NSW-WA	3
Fissurellidae	<i>Amblychilepas nigrita</i>	1-5	30	12	U	U	--	Subtidal	Qld-WA	0
Fissurellidae	<i>Diodora lineata</i>	1-5	30	12	U	U	--	Subtidal	NSW-Vic	1
Fissurellidae	<i>Tugali parmophoidea</i>	1	1	2	R	--	--	Subtidal ¹	NSW-SA	0
Fissurellidae	<i>Montfortula rugosa</i>	>500	100	13	A	A	A	Intertidal	Qld-WA, Tas	5
Trochidae	<i>Austrocochlea concamerata</i>	10-30	5	2	R	R	R	Intertidal	NSW-WA, Tas	0
Trochidae	<i>Austrocochlea porcata</i>	>500	100	13	A	A	A	Intertidal	Qld-Vic	0

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6	Trochidae	<i>Cantharidella picturata</i>	30-200	85	13	A	C	C	Intertidal	NSW	1
7	Trochidae	<i>Clanculus brunneus</i>	1-30	20	5	C	--	--	Subtidal ¹	NSW	0
8	Trochidae	<i>Clanculus clangus</i>	1-5	5	1	R	--	--	Subtidal ¹	NSW	0
9	Trochidae	<i>Clanculus floridus</i>	1-30	10	4	U	--	--	Subtidal ¹	NSW-Vic	0
10	Trochidae	<i>Granata imbricata</i>	1-50	20	6	C	U	--	Subtidal	NSW-WA	0
11	Trochidae	<i>Herpetopoma aspersa</i>	1-5	5	3	U	R	--	Subtidal	Southern Aust.	0
12	Trochidae	<i>Phasianotrochus eximius</i>	5-200	95	12	C	C	--	Subtidal	NSW-WA	0
13	Trochidae	<i>Phasianotrochus sp.</i>	1	1	1	R	--	--	-	-	0
14	Trochidae	<i>Stomatella impertusa</i>	2-10	15	5	U	U	--	Subtidal	IWP – Australia	0
15	Trochidae	<i>Tallorbis roseolus</i>	1-20	20	7	C	U	--	Subtidal	IWP- Qld	0
16	Trochidae	<i>Tallorbis roseolus</i>	1-20	20	7	C	U	--	Subtidal	IWP- Qld	0
17	Trochidae	<i>Tallorbis roseolus</i>	1-20	20	7	C	U	--	Subtidal	IWP- Qld	0
18	Turbinidae	<i>Astraliu rhodostomum</i>	1-5	2	5	R	R	--	Subtidal	IWP- Qld	0
19	Turbinidae	<i>Astraliu squamiferum</i>	10-60	15	4	U	--	--	Subtidal ¹	Southern Aust.	0
20	Turbinidae	<i>Astraliu tentoriiformis</i>	30-500	65	6	C	--	--	Subtidal ¹	Qld-NSW	2
21	Turbinidae	<i>Astraliu tentoriiformis</i>	30-500	65	6	C	--	--	Subtidal ¹	Qld-NSW	2
22	Turbinidae	<i>Turbo torquatus</i>	1-10	5	6	U	U	--	Subtidal	NSW-WA	3
23	Turbinidae	<i>Turbo undulatus</i>	20-500	100	13	A	A	--	Subtidal	WA-NSW	5
24	Turbinidae	<i>Turbo undulatus</i>	20-500	100	13	A	A	--	Subtidal	WA-NSW	5
25	Turbinidae	<i>Phasianella c.f. ventricosa</i>	1	1	1	R	--	--	Subtidal ¹	WA-NSW	0
26		Superorder Neritopsina									
27	Neritidae	<i>Nerita atramentosa</i>	>500	100	13	A	A	A	Intertidal	Qld-WA, NZ	6
28		Superorder Caenogastropoda; Order Sorbeoconcha									
29											
30	Dialidae	<i>Diala sp.</i>	1-5	2	1	R	--	--	-	-	0
31	Cerithiidae	<i>Cacozeliana granaria</i>	20-200	15	6	C	U	R	Intertidal	Southern Aust.	0
32		Superorder Caenogastropoda; Infraorder Littorinimorpha									
33											
34	Planaxidae	<i>Hinea brasiliana</i>	1-100	3	3	U	R	R	Intertidal	Qld-SA	0
35	Littorinidae	<i>Bembicium nanum</i>	>500	100	13	A	A	A	Intertidal	Qld-Tas	5
36	Littorinidae	<i>Littorina acutispira</i>	10-200	25	13	C	C	U	Intertidal	Qld-Vic	2
37	Littorinidae	<i>Littorina unifasciata</i>	>500	100	13	A	A	A	Intertidal	Qld-WA	6
38	Littorinidae	<i>Littorina unifasciata</i>	>500	100	13	A	A	A	Intertidal	Qld-WA	6
39	Littorinidae	<i>Nodilittorina pyramidalis</i>	>500	75	13	A	A	C	Intertidal	IWP	5
40	Rissoidae	<i>Rissoina c.f. fasciata</i>	5-100	25	7	C	C	U	Intertidal	Qld-Tas	0
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6	Rissoidae	<i>Rissoina c.f. crassa</i>	1-50	10	8	C	U	R	Intertidal	NSW-WA	0	
7	Vanikoridae	<i>Vanikora sigaretiformis</i>	1-2	1	1	R	R	--	Unknown	NT-NSW	0	
8	Cypraeidae	<i>Cypraea annulus</i>	1	1	1	R	--	--	Subtidal ¹	IWP	0	
9	Cypraeidae	<i>Cypraea caputserpentis</i>	1-10	10	4	U	--	--	Subtidal ¹	IWP	0	
10	Cypraeidae	<i>Cypraea clandestina</i>	1-3	2	2	R	--	--	Subtidal ¹	IWP	0	
11	Cypraeidae	<i>Cypraea erosa</i>	1	2	1	R	--	--	Subtidal ¹	IWP	0	
12	Cypraeidae	<i>Cypraea flaveola</i>	1	1	1	R	--	--	Subtidal ¹	IWP	0	
13	Triviinae	<i>Trivia merces</i>	1-5	2	1	R	--	--	Subtidal ¹	Qld-WA	0	
14	Cassidae	<i>Semicassis labiatum</i>	1-2	2	2	R	--	--	Subtidal ¹	Temperate	1	
15	Ranellidae	<i>Cabestana spenglerii</i>	1-30	90	13	C	C	--	Subtidal	Qld-SA	3	
16	Ranellidae	<i>Charonia lampas</i>	1-5	3	3	U	R	--	Subtidal	Temperate	2	
17	Ranellidae	<i>Cymatium parthenopeum</i>	1	4	5	R	R	--	Subtidal	Cosmopolitan	1	
18	Ranellidae	<i>Ranella australasia</i>	1-3	5	6	U	--	--	Subtidal ¹	NSW-WA	0	
19	Ranellidae	<i>Sassia parkinsonia</i>	1-20	5	4	U	--	--	Subtidal ¹	NSW-Tas	0	
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6	Buccinidae	<i>Nassarius c.f. jonasii</i>	1-2	1	2	R	--	R	Intertidal ²	Qld-Vic	1
7	Mitridae	<i>Mitra badia</i>	1-3	2	2	R	--	--	Subtidal ¹	NSW-WA, Tas	0
8	Mitridae	<i>Mitra carbonaria</i>	1-2	10	3	R	--	--	Subtidal ¹	NSW-WA, NZ	0
9	Conidae	<i>Conus anemone</i>	1-3	3	2	R	--	--	Subtidal ¹	NSW-WA	0
10	Conidae	<i>Conus paperliferus</i>	1-4	15	5	U	--	--	Subtidal ¹	Qld-Vic	0
11	Columbellidae	<i>Euplica versicolour</i>	1	1	1	R	--	--	Unknown	Unknown	0
12	Columbellidae	<i>Mitrella</i> spp.	10-200	85	12	A	A	--	Subtidal ¹	NSW	0
13	Columbellidae	<i>Parviterebra c.f. trinineata</i>	1	1	1	R	--	--	Subtidal ¹	Qld-SA	0
14	Marginellidae	<i>Austroginella</i> sp.	1-5	1	1	R	--	--	Subtidal ¹	SE Aust.	0
15	Marginellidae	<i>Volvarina mustelina</i>	1-10	5	5	U	U	--	Unknown	Unknown	0
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19		Superorder Heterobranchia									
20	Architectonicidae	<i>Philippia lutea</i>	1-3	3	5	U	R	--	Unknown	NSW-WA	0
21		Pulmonata						--			
22	Siphonariidae	<i>Siphonaria denticulata</i>	>500	100	13	A	A	A	Intertidal	Qld-NSW	4
23	Siphonariidae	<i>Siphonaria funiculata</i>	30-500	90	13	A	A	C	Intertidal	Qld-Tas	1
24	Siphonariidae	<i>Siphonaria zelandica</i>	30-500	35	7	C	C	U	Intertidal	NSW-WA, NZ	0
25	Onchidiidae	<i>Onchidella patelloides</i>	1	1	1	R	R	R	Intertidal	NSW-Tas, NZ	0
26											
27		Opisthobranchia									
28											
29	Aplysiidae	<i>Aplysia dactylomela</i>	1-5	3	2	R	--	--	Subtidal ¹	World wide	1
30	Aplysiidae	<i>Aplysia juliana</i>	5-200	25	8	C	C	--	Subtidal	Circumglobal	0
31	Aplysiidae	<i>Aplysia parvula</i>	1-3	4	4	U	--	--	Subtidal ¹	World wide	0
32	Aplysiidae	<i>Aplysia sydheyensis</i>	2-30	20	5	C	U	--	Subtidal	Southern Aust.	0
33	Aplysiidae	<i>Dolabrifera brazieri</i>	1-20	10	6	C	U	R	Intertidal	SE Aust., NZ	0
34	Aplysiidae	<i>Stylocheilus longicauda</i>	20-5-	2	3	R	--	--	Subtidal ¹	Circumglobal	0
35	Aplysiidae	<i>Bursatella leachii</i>	6	1	1	R	--	--	Subtidal ¹	Circumglobal	0
36	Philiidae	<i>Philine angasi</i>	6-35	1	2	R	--	--	Subtidal ²	Southern Aust., NZ	0
37											
38	Pleurobranchidae	<i>Berthellina citrina</i>	5-12	6	6	C	U	--	Subtidal	IWP	0
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6	Pleurobranchidae	<i>Pleurobranchus peroni</i>	1-2	3	4	R	R	--	Unknown	IWP	0	
7	Pleurobranchidae	<i>Pleurobranchea maculata</i>	1-8	3	5	U	R	--	Subtidal	SE Aust., NZ	0	
8	Bullinidae	<i>Bullina lineata</i>	1-10	10	4	U	--	R	Intertidal ²	IWP	0	
9	Hydatinidae	<i>Hydatina physis</i>	1-3	2	3	R	--	--	Unknown ²	Circumglobal	0	
10	Umbraculidae	<i>Umbraculum umbraculum</i>	1	3	4	R	R	--	Subtidal	IWP	0	
11	Oxynoidae	<i>Oxynoe viridis</i>	1	2	5	R	--	--	Subtidal ³	IWP	0	
12	Elysiidae	<i>Elysia australis</i>	10-35	3	4	U	--	--	Unknown ³	Circumtropical	0	
13	Polybranchiidae	<i>Polybranchia orientalis</i>	1	1	1	R	--	--	Subtidal ³	IWP	0	
14	Limapontiidae	<i>Stiliger aureomarginatus</i>	1	1	1	R	R	--	Subtidal	Western Pacific	0	
15	Dendrodorididae	<i>Dendrodoris fumata</i>	1-12	10	6	C	U	--	Subtidal	IWP	0	
16	Dendrodorididae	<i>Dendrodoris denisoni</i>	1	1	1	R	R	--	Subtidal	Indo Pacific	0	
17	Dendrodorididae	<i>Dendrodoris nigra</i>	1-5	3	3	U	R	--	Subtidal	IWP	0	
18	Dendrodorididae	<i>Doriopsilla miniata</i>	1-6	3	4	U	R	--	Subtidal	IWP	0	
19	Dendrodorididae	<i>Doriopsilla carneola</i>	1	4	7	R	R	--	Subtidal	Southern Aust.	0	
20	Dorididae	<i>Discodoris lilacina (fragilis)</i>	1-3	2	3	R	R	--	Unknown	Indian & Pacific	0	
21	Dorididae	<i>Platyodoris galbannus</i>	6-12	3	3	U	R	--	Unknown	SE Aust.	0	
22	Dorididae	<i>Hoplodoris nodulosa</i>	1	2	2	R	R	--	Subtidal	Southern Aust.	0	
23	Dorididae	<i>Jorunna pantherina</i>	1-3	4	5	U	R	--	Subtidal	Eastern Aust.	0	
24	Dorididae	<i>Jorunna sp. (purple)</i>	1	2	3	R	R	--	Subtidal	IWP	0	
25	Dorididae	<i>Rostanga arbutus (bassia)</i>	1-15	10	10	C	U	--	Unknown	NSW	0	
26	Dorididae	<i>Thordisa c.f. villosa</i>	2	1	1	R	R	--	Subtidal	IWP	0	
27	Chromodorididae	<i>Ceratosoma amoena</i>	1	3	3	R	R	--	Subtidal	Southern Aust., NZ	0	
28	Chromodorididae	<i>Glossodoris atromarginata</i>	1-2	2	2	R	R	--	Subtidal	Pacific & Indian	0	
29	Chromodorididae	<i>Hypselodoris bennetti</i>	1-6	10	5	U	U	--	Subtidal	SE Aust.	0	
30	Chromodorididae	<i>Mexichromis mariei</i>	1	1	1	R	R	--	Subtidal	West Pacific	0	
31	Polyceridae	<i>Plocampherus imperialis</i>	1	2	4	R	R	--	Subtidal	SE Aust.	0	
32	Polyceridae	<i>Polycerid sp. (unnamed sp.)</i>	1	1	1	R	R	--	Unknown	Unknown	0	
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6	Goniodorididae	<i>Goniodoris c.f. meracula</i>	25-32	4	3	U	--	--	Unknown ³	SE Aust.	0	
7	Glaucidae	<i>Austraeolis ornata</i>	1-2	5	8	R	R	--	Subtidal	Southern Aust.	0	
8	Glaucidae	<i>Glaucus atlanticus</i>	7-20	3	2	R	--	--	Planktonic	Circumglobal	0	
9	Glaucidae	<i>Glaucilla marginata</i>	5-9	2	2	R	--	--	Planktonic	Circumglobal	0	
10	Glaucidae	<i>Spurilla australis</i>	1	1	2	R	R	--	Subtidal	Southern Aust.	0	
11	Aeolidiidae	<i>Aeolidiella foulisi</i>	5-40	15	7	C	C	--	Unknown	Unknown	0	
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15	Ischnochitonidae	<i>Callochiton crocina</i>	1-6	2	2	R	R	--	Subtidal	WA-Qld, Tas, NZ	0	
16	Ischnochitonidae	<i>Ischnochiton australis</i>	2-200	85	13	A	C	--	Subtidal	Qld-Tas.	0	
17	Ischnochitonidae	<i>Ischnochiton elongatus</i>	4-200	80	12	A	C	--	Subtidal	NSW-WA, Tas.	1	
18	Ischnochitonidae	<i>Ischnochiton versicolour</i>	1-50	75	13	A	C	--	Subtidal	NSW-WA, Tas.	1	
19	Chitonidae	<i>Sypharochiton pelliserpentis</i>	30-200	100	13	A	C	U	Intertidal	NSW-Tas. NZ	4	
20	Chitonidae	<i>Onithochiton quercinus</i>	1-30	10	13	C	U	--	Subtidal	Qld-NSW, WA	4	
21	Chitonidae	<i>Rhyssoplax jugosus</i>	1-10	10	11	U	U	--	Subtidal	NSW-Vic	0	
22	Mopalidae	<i>Plaxiphora albida</i>	5-25	35	12	C	C	U	Intertidal	Qld-WA, Tas	4	
23	Acanthochitonidae	<i>Cryptoplax mystica</i>	6-35	5	5	U	U	--	Subtidal	NSW	0	
24	Acanthochitonidae	Unidentified sp. 1	2	1	1	R	--	--	-	-	0	
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30	Mytilidae	<i>Mytilus planulatus</i>	5-40	3	2	R	--	--	Subtidal ¹	NSW-WA, Tas	2	
31	Mytilidae	<i>Brachidontes rostratus</i>	35	2	1	R	--	R	Intertidal ⁴	NSW-SA, Tas	1	
32	Mytilidae	<i>Xenostrobus pulex</i>	30-80	35	8	C	C	U	Intertidal	NSW-WA, Tas	0	
33	Mytilidae	<i>Trichomya hirsuta</i>	5-50	55	7	C	C	--	Subtidal	NSW-Tas	2	
34	Pteriidae	<i>Pinctada maculata</i>	3-15	2	3	R	--	--	Subtidal ¹	NSW-Torres St.	0	
35	Anomiidae	<i>Anomia trigonopsis</i>	5	1	1	R	--	--	Subtidal ¹	Qld-NSW	0	
36	Limidae	<i>Limatula strangei</i>	1-3	3	1	R	R	--	Subtidal	Qld-WA	0	
37	Pectinidae	<i>Scaeoclamys livida</i>	1	1	1	R	--	--	Subtidal ¹	Qld-NSW	1	
38	Galeommatidae	<i>Kellia</i> sp.	1-16	10	9	C	--	--	Subtidal	Qld-Vic	1	
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	<i>Lasaea australis</i>	30-500	30	6	C	U	--	Subtidal	NSW-WA, Tas	0
Ostreidae	<i>Saccostrea glomerata</i>	30-100	95	13	A	C	U	Intertidal	Qld-Vic	5
Chamidae	<i>Chama</i> sp.	1	1	1	R	--	--	-	-	0
CLASS: CEPHALOPODA										
Octopodidae	<i>Hapalochlaena maculosa</i>	1	3	4	R	--	--	Subtidal ⁵	Qld-WA, Tas.	0
Octopodidae	<i>Octopus</i> c.f. <i>tetricus</i>	1-2	50	12	R	--	--	Subtidal	Qld-NSW	0

- [1] Likely to be more common in shallow subtidal habitats
 [2] Cryptic – burrows into sand
 [3] Cryptic – well camouflaged
 [4] More common in sections of the coast sheltered from strong wave action
 [5] Cryptic – hides and can be well camouflaged

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771 **Figure Legends**

772 *Figure 1:* The Illawarra Coast, NSW, Australia, showing the thirteen intertidal
773 study sites and the number of surveys conducted at each site.

774

775 *Figure 2:* The distribution of molluscan species recorded on intertidal reefs in
776 the Illawarra region according a) their preferred marine habitats and b) their
777 geographic distributions.

778

779 *Figure 3:* The frequency distribution of molluscan species on intertidal reefs
780 in the Illawarra region based on their; a) numerical rarity (maximum
781 abundance recorded per reef); b) spatial rarity (number of locations
782 recorded) and; c) temporal rarity (percent of surveys recorded). Frequency
783 distributions are provided for the full data set of species recorded on
784 intertidal reefs, as well as a reduced data set including only those species
785 that could be reliably recorded and for intertidal specialists only.

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787 *Figure 4:* The relative proportion of species known to occur within the
788 different a) tidal distributions and b) geographic locations that have been
789 classified as abundant, common, uncommon and rare.

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Table 1: 25% cut-off values for measures of rarity used in this study, including all species recorded on intertidal reefs, a reduced dataset that removes species likely to be under-represented in our surveys, and a dataset with only species that are known to be restricted to the intertidal zone.

	Numerical ¹			Spatial ²			Temporal ³		
	All	Reduced	Intertidal	All	Reduced	Intertidal	All	Reduced	Intertidal
Abundant	>50	>200	>500	>8	13	13	>30	>75	100
Common	11-50	21-200	201-499	5-8	7-12	13	6-30	11-75	41-99
Uncommon	3-10	4-20	36-200	3-4	5-6	7-12	3-5	4-10	11-40
Rare	1-2	1-3	1-35	1-2	1-4	1-6	1-2	1-3	1-10

¹ Individuals per reef

² Number of reefs on which species were observed

³ Percent of surveys in which species were recorded

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4 *Table 2:* The number (percent) of species classified into four categories of
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7 rarity using three different measures; 1) Numerical (N) 2) Spatial (S); 3)
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9 Temporal (T). Regional indicates rarity assigned by any one of the three
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11 measures (see text). The number of species recorded in the same category
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13 using each combination of methods is also provided, along with the overall
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15 percent of species (% species) accounted for when the requirement to
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18 satisfy two or more definitions of rarity is applied.
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Measure of Rarity	Rare	Uncommon	Common	Abundant	% species
Regional	62 (42.5)	33 (22.6)	29 (19.9)	22 (15.1)	100
N	39 (26.7)	40 (27.4)	34 (23.3)	33 (22.6)	100
S	47 (32.2)	28 (19.2)	36 (24.7)	35 (24)	100
T	46 (31.5)	37 (25.3)	31 (21.2)	32 (21.9)	100
N + S	27	12	14	23	52.1
N + T	30	20	16	24	61.6
S + T	38	17	18	26	67.8
N + S + T	27	9	11	21	46.6

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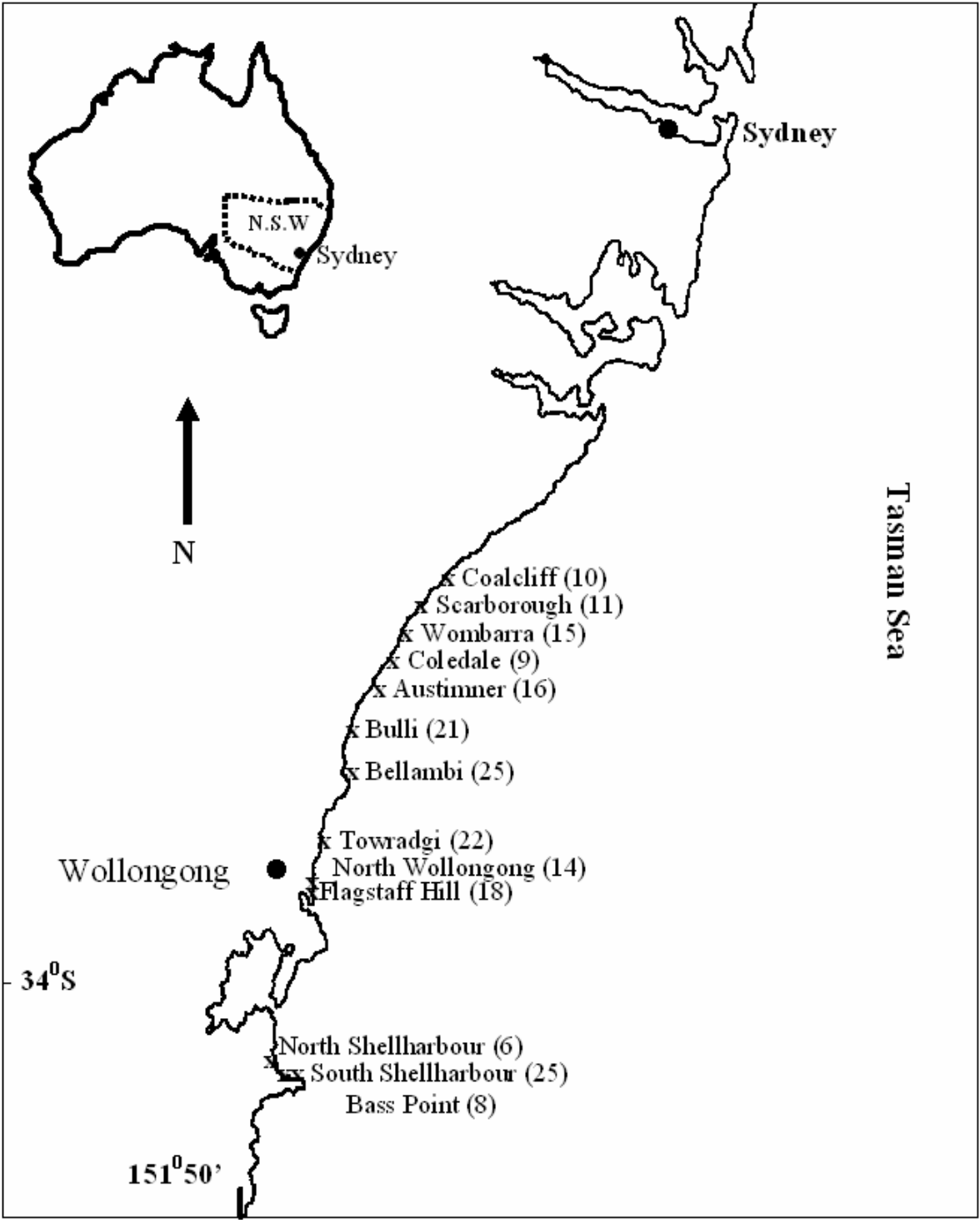
Table 3 The numbers of species classified in different rarity categories when two definitions of rarity are compared. Three definitions of rarity have been compared, based on the following measures of rarity; 1) Numerical (N) 2) Spatial (S); 3) Temporal (T). For each comparison, the differences in the classification of species has been considered in a pair-wise manner using the four rarity categories (rare, uncommon, common & abundant), such that the total number of species recorded in one category using one measure and the other category using the other measure (or vice versa) have been tallied.

	N + S	N + T	S + T
Rare – Uncommon	21	19	15
Rare – Common	9	5	2
Rare – Abundant	0	1	0
Uncommon – Common	17	16	14
Uncommon – Abundant	6	1	1
Common – Abundant	15	18	14

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4 *Table 4:* The number of regionally rare, uncommon and common species of
5 mollusc found along the Illawarra Coast from 1995-2000. The number of
6 species in each of the categories have been separated according to whether
7 they were or were not recorded in previous studies along the Illawarra Coast,
8 N.S.W. Australia (refer to Owen, 1978; Tarrant, 1980; Miskiewicz, and Lock,
9 1991; MPR, 1992; MPR, 1995; Minchinton, 1996; Waters, 1997).
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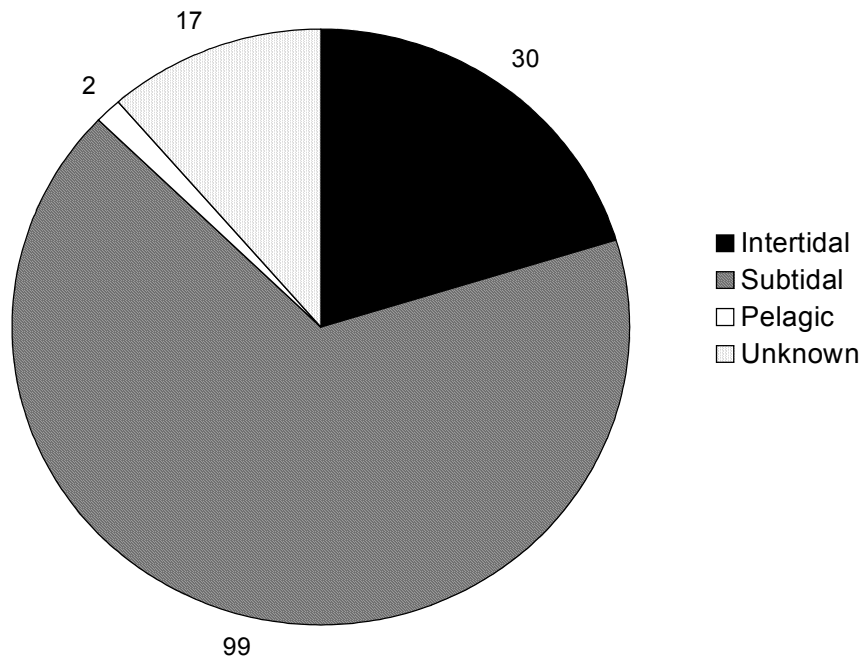
Regional rarity	Recorded in previous studies		Total number of species
	Yes	No	
Rare	7	55	62
Uncommon	4	29	33
Common	12	17	29
Abundant	19	3	22
Total no. species	42	104	146

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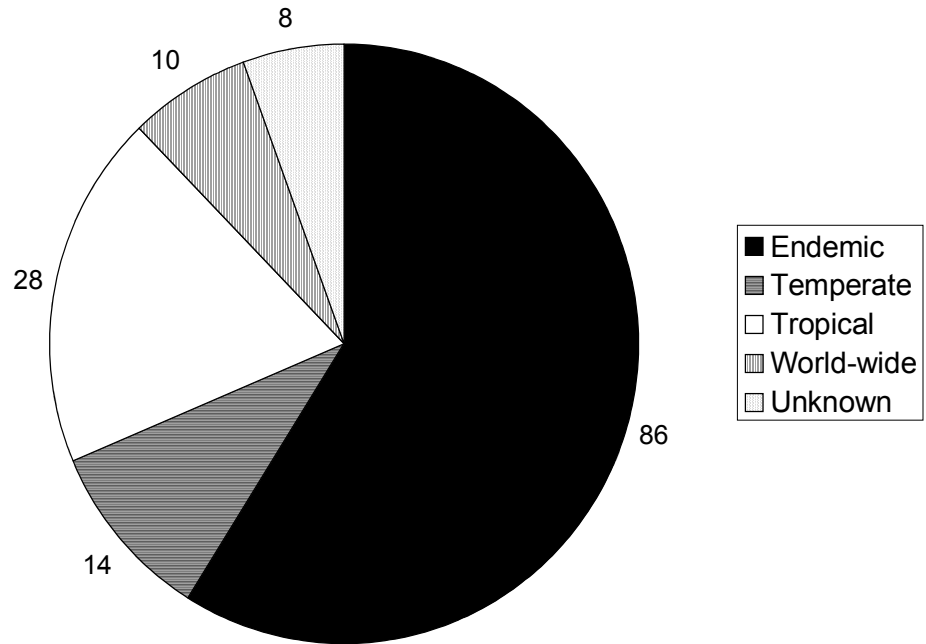


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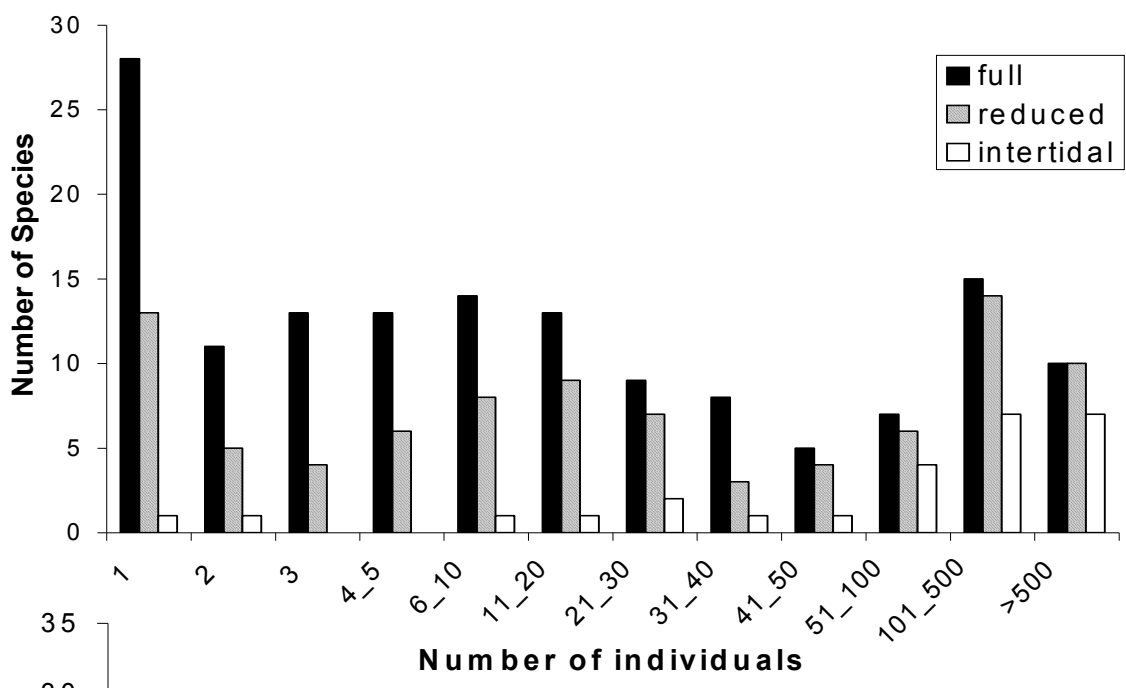


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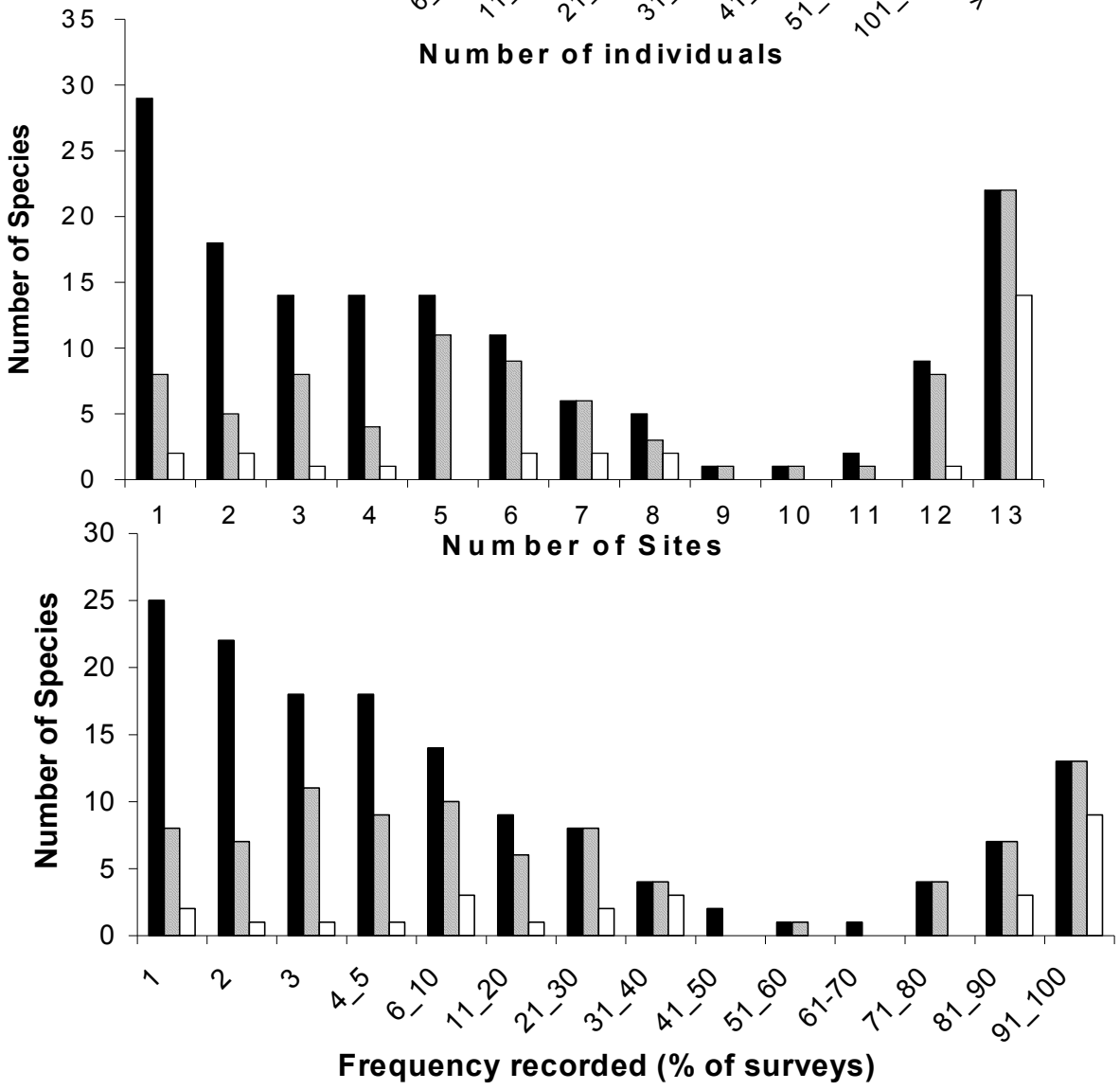


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