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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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## Abstract

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

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

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

## Introduction

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

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

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

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

Assessment of rarity in marine invertebrates also involves considerations regarding spatial scale and geographic distribution. A cautious approach to marine conservation should include the protection of regionally rare species, at least until we have a greater understanding of the genetic structure of populations on larger geographic scales. At larger scales, species that are endemic to an area will tend to have smaller distributions, and thus rarity can become closely allied to endemism (Gaston 1994). However, endemic species may be more locally abundant than many of the other species found in the area, and therefore endemism does not necessarily imply rarity (Gaston 1994). Although recent years have seen a surge in biodiversity and vulnerability studies of marine invertebrates (e.g. Bouchet et al. 2002; Gladstone 2002; O'Hara 2002; Smith 2005), there is still little data available for most marine invertebrates to assess rarity of species with broad or narrow geographic ranges (Chapman 1999, Hutchings et al. 2007).

The assessment of species rarity could also be influenced by species mobility (Davidson et al. 2004). A species that has recently immigrated from population centers outside the study area will typically be classified as rare (Hubbell and Foster 1986), primarily because it occurs at low abundances. The influence of mobility on rarity assessments has particular relevance to intertidal surveys, as some species may migrate between intertidal and subtidal habitats. Similarly, visibility can affect the assessment of species rarity, as populations of cryptic species are often overlooked and therefore underestimated (Bouchet et al. 2002).

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

The aims of this study are; 1) to practically assess the rarity of molluscs on intertidal reefs using an objective 25% ‘cut-off’; and 2) to compare rarity assignments from multiple measures of population structure with each other and with intuitive definitions for species rarity. Gaston’s lowest quartile definition was applied to numerical, spatial, and temporal rarity, as well as a combined measure of regional rarity, using three datasets: 1) a full dataset including all species recorded on intertidal reefs, 2) a reduced dataset excluding cryptic species and those observed to be more common in non-intertidal habitats, and 3) an intertidal specialist dataset including species restricted to the intertidal zone. The congruence between these measures was also analyzed to determine the relative importance of including multiple measures of rarity. Finally, rarity has been assessed at a larger geographic scale by examining the relationship between regional rarity and endemism. This is the first study to systematically assess different measures of rarity using Gaston's lower quartile criterion in marine invertebrates, and results will be important on a practical regional level by identifying rare molluscan species in south-eastern Australia. In addition, this study contributes more broadly to methodology for future monitoring and conservation management, providing guidelines for rarity assessments of marine invertebrates to facilitate appropriate marine conservation strategies.

## Methods

### *Surveys*

Surveys of the macro-molluscan fauna (> ~ 5mm excluding juveniles) were conducted on thirteen intertidal reefs along the Illawarra coast, N.S.W. Australia (Figure 1). A total of 200 independent surveys were conducted during periods of low tide (0.0-0.6m) from 1995-2000. Standardised one hour timed search surveys were used in approximately 250m$^2$ areas spanning the supralittoral to shallow subtidal zone (up to 1m below mean low tide) on each reef. The entire range of habitats was investigated at all accessible levels of the shore, including the tops and undersides of pebbles and boulders, flat rock surfaces, caves and crevices, rock pools and artificial swimming pools. The number of surveys varied at each site (see Figure 1) according to accessibility due to wave exposure. The surveys were primarily conducted during spring and summer when the tides were less than 0.3m, although some surveys were also undertaken at each site in other seasons. At least four sites were sampled during each week of low tides and the order of surveys was randomly distributed between sites, with each sites repeatedly surveyed in each year of the study. Species accumulation curves flattened at all sites within this time frame, with the exception of the three most diverse sites around Shellharbour and Bass Point (see Benkendorff and Davis 2002).

*Species identification*

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

*Species distribution*

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

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

*Assessment of species rarity*

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

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

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

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

Rarity was assessed for full, reduced and intertidal-only datasets; unless explicitly stated in the text, all values and statements hereafter relate to the full dataset. The reduced dataset includes only those species for which we believe our records are representative based observations and literature references and excludes species that were a) pelagic, b) observed more commonly along the Illawarra Coast during dives in the shallow subtidal zone or reported as common in other habitats from the literature, c) more commonly found in death assemblages washed up on adjacent shores than in our intertidal surveys, and d) easily overlooked due to camouflage or cryptic habitats (refer to Appendix 1).

### *Statistical analysis*

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

## Results

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

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

### *Single measures of rarity*

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

The first quartile for spatial rarity in the full dataset included only those species recorded at one or two sites (Table 1, Figure 3b). Based on this cut-off value, 47 species (32.2%) have been classified as rare (Table 2, Appendix 1). A large proportion of species were only observed on one reef, whereas another group of species were observed on every reef that was surveyed, and the associated frequency distribution is bimodal (Figure 3b).

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

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

### *Multiple measures of rarity*

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

Most of the differences in the classifications between methods involved adjacent rarity categories. For example, species were recorded as rare using one method and uncommon using another (Table 3). However, two species were classified as rare using at least one method and abundant using another (Table 3). One of these species (*Octopus tetricus*) was classified as numerically rare but was observed on nearly every reef in the region and was recorded in 50% of all surveys. On the other hand, *Stylocheilus longicauda* was found to be numerically abundant, but temporally rare. A further four numerically-rare species were classified as common based on the number of locations at which they were recorded (*Cymatium parthenopeum*, *Oxynoe viridis*, *Doriopsilla carneola, Austraeolis ornata*).

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

*Impact of distribution on rarity assessment*

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

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

## Discussion

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

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

Application of quartile cut-offs can also contribute towards understanding the distribution of rare species within a particular assemblage. For each of the three measures of population structure used in this study, frequency distributions for all molluscs found on intertidal reefs in the Illawarra region are skewed to the right. This pattern is consistent with previous studies on a wide range of communities, whereby most species are represented by low numbers of individuals and most of the individuals belong to a few abundant species (e.g. Fisher et al. 1943; MacArthur 1957). In contrast, the frequency distribution for species abundance using exclusively intertidal species was skewed to the left, indicating a large proportion of common or abundant species are well adapted to intertidal reefs. The frequency distributions for spatial and temporal occurrence of the intertidal dataset are bimodal, indicating that there is one group of molluscs whose presence is entirely predictable on intertidal reefs, while many other species are highly unpredictable in space and time.

Multiple measures of population structure for rarity assessment are advantageous because they encompass several variables that may influence species dominance in an assemblage. In this study there was only 52-68% overlap in the classifications of species using three different measures, suggesting that each of these is representing a different component of rarity within the assemblage. Previous authors have recognized as many as seven different forms of rarity in terrestrial organisms, which incorporate aspects of population size, range and habitat specificity (e.g. Rabinowitz et al. 1986; Yu and Dobson 2000). However, these types of studies require significant knowledge of the species and their niche requirements across a large geographic scale and are therefore difficult to apply to many marine invertebrates. Regardless of the measures used in rarity assessments, spatial and temporal replication is crucial when designing surveys for the conservation of marine invertebrates, because regionally rare species are generally less likely to be detected. Only a small proportion of the molluscs that were classed as rare in this study have been previously recorded along the Illawarra Coast in snap shot surveys of species richness for environmental management purposes (Owen 1978; Miskiewicz and Lock 1991; Marine Pollution Research 1992; 1995; Minchinton 1996; Waters 1997). Rarity significantly influenced the likelihood that molluscs were included in previous species lists ($\chi^2 = 50.2$, $p < 0.001$). *A priori* knowledge of the different types of rare species that occur within a bioregion will enable targeted studies at particular sites of interest for future environmental impact assessment.

Cryptic species habits and the interconnectedness of intertidal and subtidal habitats create further problems for assessing the rarity of species on intertidal reefs. The results from our reduced datasets suggest when those species that can not be reliably assessed in the intertidal zone are excluded, the cut-off values for rarity categories increase. In particular, mobility across tidal zones must be considered in these rarity analyses, because most of the species classified as rare by all three measures in our study are known to inhabit the subtidal region. Such species are often termed incidentals, vagrants, or immigrants (Gaston 1994) because they do not appear to maintain viable populations in the study area. From an ecological perspective, immigrants should be regarded as a part of the community because they could contribute to species interactions (Gaston 1994). However, from a conservation perspective, rare immigrants should usually be ignored because there are likely to be other areas that are more effective for their conservation. Species that are both rare and restricted to intertidal reefs should be considered of highest priority for intertidal conservation (e.g. *Onchidella patelloides*). However, further studies are required on other rare species to measure their abundance in subtidal habitats, specific habitat requirements and other life history characteristics. The possibility that intertidal reefs provide refuge or breeding habitat for some subtidal species should not be overlooked (e.g. Rodgers et al. 1995; Benkendorff and Davis 2004).

The ability to detect the presence of rare species is particularly important for the conservation and management of biological resources (Terborogh and Winter 1980; Gaston 1994; van Jaarsveld et al. 1998), and the type of rarity will help determine the appropriate conservation response. Species that are rare in space or time may require a different form of conservation planning compared to species with consistently low local abundances. Spatially-rare species are potential habitat specialists restricted by the availability of suitable sites (e.g. boulder fields, Chapman and Underwood 1996; Benkendorff and Davis 2004). Habitat specialists are potentially vulnerable to stressors that negatively impact their habitat, such as recreational activities like trampling and over-turning boulders, pollutants and agricultural run-off. For these species, attempts should be made to identify and protect those features of the environment that restrict them to specialized locations. On the other-hand, temporally rare species could be migratory species or species that spend extended periods of time as pelagic larvae (e.g. Kempf 1981). These species may therefore be more sensitive to changes in ocean circulation and phytoplankton availability resulting from rising global temperatures or off-shore activities. A better understanding of where these species occur when not on intertidal reefs may be necessary for their conservation.

The number of species treated as rare will vary greatly between studies, not only due to lack of consistency in the application of standardized criteria to assign rarity, but also due to the ranges and life histories of species included in the datasets The majority of species recorded in this study appear to be endemic to Australia (60%), compared to previous studies that have found less than 10% endemicity in molluscs from other parts of Australia (e.g. Northern Australia, Wells 1990; Heron Island, Marshall and Willan 1999; Victorian short range endemics, O’Hara 2002). A major focus for intertidal molluscan conservation in Australia should perhaps be the few rare endemics that are restricted to the intertidal zone (e.g. *Dolabrifera brazieri* and *Hinea brasiliana*). Additionally, several regionally-rare species have unknown geographic and/or tidal distributions and should also be priority targets for future research (Appendix 1). Reproductive strategy and differential recruitment may be other factors influencing molluscan distributions and rarity on temperate Australian reefs. Broadcast spawners and species with pelagic larvae are likely to have broader spatial distributions than brooders or direct developers from benthic egg masses (e.g. Scheltema 1989; Benkendorff and Davis 2004; Johnson et al. 2001). Populations of direct developers may therefore be more sensitive to temporary or stochastic change, such as pollutants, storms, or temperature extremes, than populations of planktotrophs, which can more readily recolonise areas after a disturbance via pelagic larval recruitment. However, the regional rarity of species with dispersive larvae will depend on where the source populations occur. In this study, a significantly higher proportion of the regionally-abundant species are endemic, whereas the majority of rare species have distributions extending beyond Australian waters. Endemic species are expected to be self-replenishing, producing a large number of recruits at a regional scale, whereas species with tropical and cosmopolitan distributions may depend on the southern dispersal of pelagic larvae via the East Australian Current. The East Australian Current has a seasonal cycle with a strong southward flow of warm water during the austral summer (Ridgway & Godfrey 1997) moving parallel to the Illawarra Coast, but with anticyclonic (warm core) eddies (Tomczak and Godfrey 1994) providing episodic pulses of warm water and potential recruits. This is consistent with the temporally and numerically rare occurrence of most tropical species in this region.

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

Conservation strategies should not only account for multiple types of rarity, but also incorporate measures of community assessment including species richness, habitat specificity, reproductive strategies and endemism (Awad et al. 2002; Benkendorff and Davis 2002; Benkendorff and Davis 2004). In this study, a large proportion of molluscs were found to be rare, but only one of these species is currently protected from collection on intertidal reefs in N.S.W., Australia; the numerically rare species, *Octopus tetricus* (N.S.W. Fisheries Management Act, 1994). The lack of knowledge about life history, ecology, biogeography and human impacts for most marine invertebrate species likely hinders appropriate conservation strategies. Furthermore, comprehensive studies on species rarity in different locations and ecosystems will be labour intensive, requiring replicated quantitative surveys, such as reported here. This is unlikely to be compatible with rapid biodiversity assessment programs, such as those championed by Conservation International (e.g. Willink et al. 2004). Nevertheless, rapid "snap shot" surveys can be used to assess spatial distribution and subjectively rank species according to their numerical abundance (e.g. Benkendorff 2005). In this way, species in the lower quartile for numerical and spatial rarity can be targeted for more in-depth studies. Once rare species are identified, the underlying causes of rarity should be investigated to determine the appropriate management strategy. Standardized assessment of multiple measures for rarity across a range of habitats and ecosystems will complement rapid biodiversity assessment for conservation purposes and provide an important step towards suitable management of potentially vulnerable species.

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## Literature Cited

Angel A, Branch GM, Wanless RM, Siebert T (2006) Causes of rarity and range restriction of an endangered, endemic limpet, *Siphonaria compressa*. J Exp Mar Biol Ecol 330: 245-260

Awad AA, Griffiths CL, Turple JK (2002) Distribution of South African marine benthic invertebrates applied to the selection of priority conservation areas. Divers Distrib 8: 129-145

Barnes RSK (2005) Interspecific competition and rarity in mudsnails: feeding interactions between and within *Hydrobia acuta neglecta* and sympatric *Hydrobia* species. Aquat Conserv 15: 485-49.

Beesley PL, Ross GJB, Wells A (1998) Mollusca the Southern Synthesis. CSIRO Publishing, Melbourne

Benkendorff K (2005) Intertidal molluscan and echinoderm diversity at Althorpe Island and Innes National Park, South Australia. T Roy Soc South Aust 129: 145-157

Benkendorff K, Davis AR (2002) Identifying hotspots of molluscan species richness on rocky intertidal reefs. Biodivers Conserv 11: 1959-1973

Benkendorff K, Davis AR (2004). Gastropod egg mass deposition on a temperate, wave-exposed coastline in New South Wales, Australia: implications for intertidal conservation. Aquat Conserv 14: 263-280

Bouchet P, Lozouet P, Maestrati P, Heros V (2002) Assessing the magnitude of species richness in tropical marine environments: exceptionally high numbers of molluscs at a New Caledonia site. Biol J Linn Soc 75: 421-436

Chapman MG (1999) Are there adequate data to assess how well theories of rarity apply to marine invertebrates? Biodivers Conserv 8: 1295-1318

Chapman MG & Underwood AJ (1996) Experiments on effects of sampling biota under intertidal and shallow subtidal boulders. J Exp Mar Biol Ecol 207: 103-126

Connell JH (1972) Community interactions on marine rocky intertidal shores. Annu Rev Ecol Syst 3: 169-192

Davidson IC, Crook AC, Barnes DKA (2004) Quantifying spatial patterns of intertidal biodiversity: Is movement important? PSZNI Mar Ecol 25: 15-34

Edgar GJ (1997) Australian Marine Life, the plants and animals of temperate waters. Reed Books, Victoria

Fagan WF, Kennedy CM, Unmack PJ (2005) Quantifying Rarity, Losses, and Risks for Native Fishes of the Lower Colorado River Basin: Implications for Conservation Listing. Conserv Biol 19: 1872–1882

Fisher RA, Corbet AS, Williams CB (1943) The relationship between the number of species and the number of individuals in a random sample of an animal population. J Anim Ecol 12: 42-58

Gladstone W (2002) The potential value of indicator groups in the selection of marine reserves. Biol Conserv 104: 211-220

Gaston KJ (1994) *Rarity*. Chapman and Hall, Melbourne.

Helmuth B, Mieszkowska N, Moore P, Hawkins S (2006) Living on the edge of two changing worlds: forecasting the responses of rocky intertidal ecosystems to climate change. Ann Rev Ecol Evol Sys 37: 373-404

Hubbell SP, Foster RB (1986) Commonness and rarity in a neotropical forest: Implications for tropical tree conservation. In: Soulé MA (ed) Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland

Hutchings P, Ahyong S, Byrne M, Przeslawski R, Wörheide G (2007) Vulnerability of benthic marine invertebrates of the Great Barrier Reef to climate change. In: Johnson J, Marshall R (eds) Climate Change and the Great Barrier Reef: A Vulnerability Assessment. Great Barrier Reef Marine Park Authority, Townsville.

Jansen P (2000) Seashells of South-East Australia. Capricornica Publications, Lindfield

Johnson MP, Allcock AL, Pye SE, Chambers SJ (2001) The effects of dispersal mode on the spatial distribution patterns of intertidal molluscs. J Anim Ecol 70: 641-649

Kempf SC (1981) Long-lived larvae of the gastropod *Aplysia juliana*: Do they disperse and metamorphose or just fade away? Mar Ecol Prog Ser 6: 61-66

Lamprell K, Healy J (1998) Bivalves of Australia, Volume 2. Backhuys Publishers, Leiden

Lamprell K, Whitehead T (1992) Bivalves of Australia, Volume 1. Crawford House Press, Bathurst

Laurance WF (1991) Ecological correlates of extinction proneness in Australian tropical rain forest mammals. Conservation Biology 5: 79-89.

MacArthur RH (1957) On the relative abundance of bird species. Proc Natl Acad Sci USA 43: 373-387

Marine Pollution Research Pty Ltd (1992) Marine Ecology of Scarborough/Wombarra Beach: Report on the Possible impacts of a proposed stormwater tunnel draining over Wombarra Beach. Snowy Mountains Engineering Corporation, NSW Australia

Marine Pollution Research Pty Ltd. (1995) Ecological Survey and Assessment of Marine Ecological Impacts, Appendix 11 Environmental Impact Statement: Shell Cove Boatharbour/Marina, The Walker Corporation and the Council of Shellharbour, Main Report. LFA (Aust) Pty Ltd, Edgecliff, NSW

Marshall JG, Willan RC (1999) Nudibranchs or Heron Island, Great Barrier Reef. A Survey of the Opisthobranchia (Sea Slugs) of Heron and Wistari Reefs. Backhuys Publishers, Leiden.

Maurer D, Gerlinger T, Robertson G (1999) Rare species as bioindicators in marine monitoring. B South Calif Acad Sci 93: 91-102

McGowan JA, Walker PW (1979) Structure of copepod community of the North Pacific central gyre. Ecol Monogr 49: 195-226

Minchinton TE (1996) Rocky Intertidal Shores. In : Minchinton TE and Whelan RJ (eds) Ecological Study of Wollongong Harbour, North Wollongong Beach, Fairy Creek and Lagoon, and Stuart and J.P. Galvin Parks. Australia Flora and Fauna Research Centre, University of Wollongong, NSW

Miskiewicz AG, Lock N (1991) Intertidal Communities. In: Marine Investigations for the Bellambi and Port Kembla Sewage Treatment Plant Upgrading, Volume 2. Biology, sediments and water quality. Environmental Management Unit, Water Board, NSW

O'Hara T (2002) Endemism, rarity and vulnerability of marine species along a temperate coastline. Invert Syst 16: 671-684

Owen PC (1978) Intertidal and sublittoral zones. In: Austin MP & Cocks KD (eds) Land Use on the South Coast of New South Wales. Volume 2 Bio-physical background studies. CSIRO Publishing, Melbourne

Rabinowitz D, Cairns S, Dillon T (1986) Seven forms of rarity and their frequency in the flora of the British Isles. In: Soulé MA (ed) Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland

Ridgway KR, Godfrey JS (1997) Seasonal cycle of the East Australian Current. J Geophys Res–Oceans 102: 22921-22936

Rodgers CN, Steinberg PD, de Nys R (1995) Factors associated with oligophagy in two species of sea hare. J Exp Mar Biol Ecol 192: 47-73

Rogers-Bennett L (2007) Is climate change contributing to range reductions and localized extinctions in northern (*Haliotis kamtschatkana*) and flat (*Haliotis walallensis*) abalones? Bull Mar Sci 81: 283-296

Rudman, W. Seaslug Forum. Australian Museum [Accessed March 2008]. http://www.seaslugforum.net

Shin PKS, Ellingsen KE (2004) Spatial patterns of soft-sediment benthic diversity in subtropical Hong Kong waters. Mar Ecol Prog Ser 276: 25-35

Scheltema RS (1989). Planktonic and non-planktonic development among prosobranch gastropods and its relationship to the geographic range of species. In: Ryland JS and PA Tyler (eds) Reproduction, Genetics and Distribution of Marine Organisms. Olsen & Olsen, Fredensborg, Denmark.

Schlacher TA, Newell P, Clavier J, Schlacher-Hoenlinger MA, Chevillon C, Britton J (1998) Soft-sediment benthic community structure in a coral reef lagoon – the prominence of spatial heterogeneity and ‘spot endemism’. Mar Ecol Prog Ser 174: 159-174

Soulé ME (1986) Conservation Biology and the “Real World”. In: Soulé MA (ed) Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland

Smith SDA (2005) Rapid assessment of invertebrate biodiversity on rocky shores: where there’s a whelk there’s a way. Biodivers Conserv 14: 3565-3576

Terborgh J, Winter B (1980) Some causes of extinction. In: Soulé MA (ed) Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland

Tomczak M, Godfrey JS (1994) Regional Oceanography: An Introduction. Pergamon. Great Britain.

Underwood AJ (1998) Phylum Mollusca: Molluscs on rocky shores. In: Beesley PL, Ross GLB & Wells A (eds) Mollusca the Southern Synthesis. Fauna of Australia, Vol. 5. CSIRO Publishing, Melbourne

Underwood AJ, Chapman MG (1998) Spatial analyses of intertidal assemblages on sheltered rocky shores. Austral Ecol 23: 138-157

Usher MB (1986) Wildlife conservation evaluation: Attributes, criteria and values. In: Usher MB (ed) Wildlife Conservation Evaluation. Chapman & Hall, London.

van Jaarsveld AS, Freitag S, Chown SL, Muller C, Koch S, Hull H, Bellamy C, Krüger M, Endrödy-Younga S, Mansell MW, Scholtz CH (1998)

Biodiversity assessment and conservation strategies. Science 279: 2106-2108

Waters S (1997) Rocky Intertidal Shores. In: Brown C and Whelan R (eds) Ecological Study of Stanwell Park Recreation Reserve and Beach. Australian Flora and Fauna Research Centre, University of Wollongong, NSW

Wells FE (1990) Comparative zoogeography of marine molluscs from northern Australia, New Guinea and Indonesia. Veliger 33: 140-144

Willink P W, Chernoff B, McCullough J (2004) A Biological Assessment of the Aquatic Ecosystems of the Pastaza River Basin, Ecuador and Peru. RAP Bulletin of Biological Assessment 33: 250 p Conservation International.

Wilson B (1993) Australian Marine Shells, Parts A &B. Odyssey Publishing. Kallaroo, Western Australia.

Yu J, Dobson FS (2000) Seven forms of rarity in mammals. J Biogeogr 27: 131-139

**Appendix:** List of species found in this study, including rarity assessments. See text for definition of local abundance, % of surveys, and number of sites. Regional rarity was assessed on full, reduced and intertidal-only datasets. A = Abundant; 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 Pattellogastropoda** | | | | | | | | | | |
| Patellidae | *Patella peronii* | >500 | 100 | 13 | A | A | -- | Subtidal[1] | NSW-WA | 1 |
| Patellidae | *Patella chapmani* | 0-20 | 5 | 2 | R | -- | -- | Subtidal | NSW-SA, Tas. | 0 |
| Patellidae | *Cellana tramoserica* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-SA | 5 |
| Acmaeidae | *Notoacmaea petterdi* | 50-200 | 85 | 13 | A | C | C | Intertidal | SE Aust | 4 |
| Acmaeidae | *Patelloida alticostata* | 20-100 | 30 | 12 | C | C | -- | Subtidal | NSW-WA | 3 |
| Acmaeidae | *Patelloida* cf. *mufria* | 1-20 | 50 | 11 | C | -- | -- | Subtidal[1] | NSW-WA | 1 |
| SUBCLASS ORTHOGASTROPODA **Superorder Vetigastropoda** | | | | | | | | | | |
| Haliotidae | *Haliotis rubra* | 1-3 | 5 | 8 | U | -- | -- | Subtidal[1] | NSW-SA | 2 |
| Haliotidae | *Haliotis coccoradiata* | 1-3 | 3 | 3 | U | -- | -- | Subtidal[1] | NSW-Vic | 0 |
| Fissurellidae | *Scutus antipodes* | 1-30 | 75 | 12 | C | C | -- | Subtidal | NSW-WA | 3 |
| Fissurellidae | *Amblychilepas nigrita* | 1-5 | 30 | 12 | U | U | -- | Subtidal | Qld-WA | 0 |
| Fissurellidae | *Diodora lineata* | 1-5 | 30 | 12 | U | U | -- | Subtidal | NSW-Vic | 1 |
| Fissurellidae | *Tugali parmophoidea* | 1 | 1 | 2 | R | -- | -- | Subtidal[1] | NSW-SA | 0 |
| Fissurellidae | *Montfortula rugosa* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-WA, Tas | 5 |
| Trochidae | *Austrocochlea concamerata* | 10-30 | 5 | 2 | R | R | R | Intertidal | NSW-WA, Tas | 0 |
| Trochidae | *Austrocochlea porcata* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-Vic | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trochidae | *Cantharidella picturata* | 30-200 | 85 | 13 | A | C | C | Intertidal | NSW | 1 |
| Trochidae | *Clanculus brunneus* | 1-30 | 20 | 5 | C | -- | -- | Subtidal[1] | NSW | 0 |
| Trochidae | *Clanculus clangus* | 1-5 | 5 | 1 | R | -- | -- | Subtidal[1] | NSW | 0 |
| Trochidae | *Clanculus floridus* | 1-30 | 10 | 4 | U | -- | -- | Subtidal[1] | NSW-Vic | 0 |
| Trochidae | *Granata imbricata* | 1-50 | 20 | 6 | C | U | -- | Subtidal | NSW-WA | 0 |
| Trochidae | *Herpetopoma aspersa* | 1-5 | 5 | 3 | U | R | -- | Subtidal | Southern Aust. | 0 |
| Trochidae | *Phasianotrochus eximius* | 5-200 | 95 | 12 | C | C | -- | Subtidal | NSW-WA | 0 |
| Trochidae | *Phasianotrochus* sp. | 1 | 1 | 1 | R | -- | -- | - | - | 0 |
| Trochidae | *Stomatella impertusa* | 2-10 | 15 | 5 | U | U | -- | Subtidal | IWP – Australia | 0 |
| Trochidae | *Tallorbis roseolus* | 1-20 | 20 | 7 | C | U | -- | Subtidal | IWP- Qld | 0 |
| Turbinidae | *Astralium rhodostomum* | 1-5 | 2 | 5 | R | R | -- | Subtidal | IWP- Qld | 0 |
| Turbinidae | *Astralium squamiferum* | 10-60 | 15 | 4 | U | -- | -- | Subtidal[1] | Southern Aust. | 0 |
| Turbinidae | *Astralium tentoriiformis* | 30-500 | 65 | 6 | C | -- | -- | Subtidal[1] | Qld-NSW | 2 |
| Turbinidae | *Turbo torquatus* | 1-10 | 5 | 6 | U | U | -- | Subtidal | NSW-WA | 3 |
| Turbinidae | *Turbo undulatus* | 20-500 | 100 | 13 | A | A | -- | Subtidal | WA-NSW | 5 |
| Turbinidae | *Phasianella* c.f. *ventricosa* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | WA-NSW | 0 |
| **Superorder Neritopsina** | | | | | | | | | | |
| Neritidae | *Nerita atramentosa* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-WA, NZ | 6 |
| **Superorder Caenogastropoda; Order Sorbeoconcha** | | | | | | | | | | |
| Dialidae | *Diala* sp. | 1-5 | 2 | 1 | R | -- | -- | - | - | 0 |
| Cerithiidae | *Cacozeliana granaria* | 20-200 | 15 | 6 | C | U | R | Intertidal | Southern Aust. | 0 |
| **Superorder Caenogastropoda; Infraorder Littorinimorpha** | | | | | | | | | | |
| Planaxidae | *Hinea brasiliana* | 1-100 | 3 | 3 | U | R | R | Intertidal | Qld-SA | 0 |
| Littorinidae | *Bembicium nanum* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-Tas | 5 |
| Littorinidae | *Littorina acutispira* | 10-200 | 25 | 13 | C | C | U | Intertidal | Qld-Vic | 2 |
| Littorinidae | *Littorina unifasciata* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-WA | 6 |
| Littorinidae | *Nodilittorina pyramidalis* | >500 | 75 | 13 | A | A | C | Intertidal | IWP | 5 |
| Rissoidae | *Rissoina* c.f. *fasciata* | 5-100 | 25 | 7 | C | C | U | Intertidal | Qld-Tas | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Rissoidae | *Rissoina* c.f. *crassa* | 1-50 | 10 | 8 | C | U | R | Intertidal | NSW-WA | 0 |
| Vanikoridae | *Vanikora sigaretiformis* | 1-2 | 1 | 1 | R | R | -- | Unknown | NT-NSW | 0 |
| Cypraeidae | *Cypraea annulus* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | IWP | 0 |
| Cypraeidae | *Cypraea caputserpentis* | 1-10 | 10 | 4 | U | -- | -- | Subtidal[1] | IWP | 0 |
| Cypraeidae | *Cypraea clandestina* | 1-3 | 2 | 2 | R | -- | -- | Subtidal[1] | IWP | 0 |
| Cypraeidae | *Cypraea erosa* | 1 | 2 | 1 | R | -- | -- | Subtidal[1] | IWP | 0 |
| Cypraeidae | *Cypraea flaveola* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | IWP | 0 |
| Triviinae | *Trivia merces* | 1-5 | 2 | 1 | R | -- | -- | Subtidal[1] | Qld-WA | 0 |
| Cassidae | *Semicassis labiatum* | 1-2 | 2 | 2 | R | -- | -- | Subtidal[1] | Temperate | 1 |
| Ranellidae | *Cabestana spenglerii* | 1-30 | 90 | 13 | C | C | -- | Subtidal | Qld-SA | 3 |
| Ranellidae | *Charonia lampas* | 1-5 | 3 | 3 | U | R | -- | Subtidal | Temperate | 2 |
| Ranellidae | *Cymatium parthenopeum* | 1 | 4 | 5 | R | R | -- | Subtidal | Cosmopolitan | 1 |
| Ranellidae | *Ranella australasia* | 1-3 | 5 | 6 | U | -- | -- | Subtidal[1] | NSW-WA | 0 |
| Ranellidae | *Sassia parkinsonia* | 1-20 | 5 | 4 | U | -- | -- | Subtidal[1] | NSW-Tas | 0 |
| **Superorder Caenogastropoda; Infraorder Ptenoglossa** |  |  |  |  |  |  |  |  |  |  |
| Epitoniidae | *Epitonium delicatulum* | 1-3 | 4 | 3 | U | -- | -- | Subtidal[1] | Qld-SA | 0 |
| Epitoniidae | *Opalia australis* | 1-2 | 2 | 1 | R | -- | -- | Subtidal[1] | Southern Aust. | 0 |
| Epitoniidae | *Opalia ballinensis* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | NSW | 0 |
| **Superorder Caenogastropoda; Infraorder Neogastropoda** |  |  |  |  |  |  |  |  |  |  |
| Muricidae | *Agnewia tritoniformis* | 1-40 | 35 | 6 | C | U | -- | Subtidal | NSW-Tas, NZ | 1 |
| Muricidae | *Bedeva hanleyi* | 1-20 | 25 | 6 | C | U | -- | Subtidal | Qld-SA | 0 |
| Muricidae | *Dicathais orbita* | 5-100 | 90 | 13 | A | C | -- | Subtidal | Qld-WA, Tas, NZ | 5 |
| Muricidae | *Ergalatax contracta* | 1-5 | 5 | 2 | R | -- | -- | Subtidal[1] | IWP | 0 |
| Muricidae | *Lepsiella reticulata* | 2-30 | 6 | 5 | C | U | -- | Subtidal | Bass Straight | 0 |
| Muricidae | *Morula marginalba* | >500 | 100 | 13 | A | A | -- | Intertidal | Eastern Aust. | 5 |
| Buccinidae | *Cominella eburnea* | 1 | 2 | 1 | R | -- | -- | Subtidal[1] | NSW-WA | 0 |
| Buccinidae | *Engina australis* | 1-10 | 4 | 4 | U | -- | -- | Subtidal[1] | NSW-Vic | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Buccinidae | *Nassarius* c.f. *jonasii* | 1-2 | 1 | 2 | R | -- | R | Intertidal[2] | Qld-Vic | 1 |
| Mitridae | *Mitra badia* | 1-3 | 2 | 2 | R | -- | -- | Subtidal[1] | NSW-WA, Tas | 0 |
| Mitridae | *Mitra carbonaria* | 1-2 | 10 | 3 | R | -- | -- | Subtidal[1] | NSW-WA, NZ | 0 |
| Conidae | *Conus anemone* | 1-3 | 3 | 2 | R | -- | -- | Subtidal[1] | NSW-WA | 0 |
| Conidae | *Conus paperliferus* | 1-4 | 15 | 5 | U | -- | -- | Subtidal[1] | Qld-Vic | 0 |
| Columbellidae | *Euplica versicolour* | 1 | 1 | 1 | R | -- | -- | Unknown | Unknown | 0 |
| Columbellidae | *Mitrella* spp. | 10-200 | 85 | 12 | A | A | -- | Subtidal[1] | NSW | 0 |
| Columbellidae | *Parviterebra* c.f. *trinineata* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | Qld-SA | 0 |
| Marginellidae | *Austroginella* sp. | 1-5 | 1 | 1 | R | -- | -- | Subtidal[1] | SE Aust. | 0 |
| Marginellidae | *Volvarina mustelina* | 1-10 | 5 | 5 | U | U | -- | Unknown | Unknown | 0 |
| **Superorder Heterobranchia** | | | | | | | | | | |
| Architectonicidae | *Philippia lutea* | 1-3 | 3 | 5 | U | R | -- | Unknown | NSW-WA | 0 |
| **Pulmonata** | | | | | | | -- | | | |
| Siphonariidae | *Siphonaria denticulata* | >500 | 100 | 13 | A | A | A | Intertidal | Qld-NSW | 4 |
| Siphonariidae | *Siphonaria funiculata* | 30-500 | 90 | 13 | A | A | C | Intertidal | Qld-Tas | 1 |
| Siphonariidae | *Siphonaria zelandica* | 30-500 | 35 | 7 | C | C | U | Intertidal | NSW-WA, NZ | 0 |
| Onchidiidae | *Onchidella patelloides* | 1 | 1 | 1 | R | R | R | Intertidal | NSW-Tas, NZ | 0 |
| **Opisthobranchia** | | | | | | | | | | |
| Aplysiidae | *Aplysia dactylomela* | 1-5 | 3 | 2 | R | -- | -- | Subtidal[1] | World wide | 1 |
| Aplysiidae | *Aplysia juliana* | 5-200 | 25 | 8 | C | C | -- | Subtidal | Circumglobal | 0 |
| Aplysiidae | *Aplysia parvula* | 1-3 | 4 | 4 | U | -- | -- | Subtidal[1] | World wide | 0 |
| Aplysiidae | *Aplysia sydneyensis* | 2-30 | 20 | 5 | C | U | -- | Subtidal | Southern Aust. | 0 |
| Aplysiidae | *Dolabrifera brazieri* | 1-20 | 10 | 6 | C | U | R | Intertidal | SE Aust., NZ | 0 |
| Aplysiidae | *Stylocheilus longicauda* | 20-5- | 2 | 3 | R | -- | -- | Subtidal[1] | Circumglobal | 0 |
| Aplysiidae | *Bursatella leachii* | 6 | 1 | 1 | R | -- | -- | Subtidal[1] | Circumglobal | 0 |
| Philinidae | *Philine angasi* | 6-35 | 1 | 2 | R | -- | -- | Subtidal[2] | Southern Aust., NZ | 0 |
| Pleurobranchidae | *Berthellina citrina* | 5-12 | 6 | 6 | C | U | -- | Subtidal | IWP | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Pleurobranchidae | *Pleurobranchus peroni* | 1-2 | 3 | 4 | R | R | -- | Unknown | IWP | 0 |
| Pleurobranchidae | *Pleurobranchea maculata* | 1-8 | 3 | 5 | U | R | -- | Subtidal | SE Aust., NZ | 0 |
| Bullinidae | *Bullina lineata* | 1-10 | 10 | 4 | U | -- | R | Intertidal[2] | IWP | 0 |
| Hydatinidae | *Hydatina physis* | 1-3 | 2 | 3 | R | -- | -- | Unknown[2] | Circumglobal | 0 |
| Umbraculidae | *Umbraculum umbraculum* | 1 | 3 | 4 | R | R | -- | Subtidal | IWP | 0 |
| Oxynoidae | *Oxynoe viridis* | 1 | 2 | 5 | R | -- | -- | Subtidal[3] | IWP | 0 |
| Elysiidae | *Elysia australis* | 10-35 | 3 | 4 | U | -- | -- | Unknown[3] | Circumtropical | 0 |
| Polybranchiidae | *Polybranchia orientalis* | 1 | 1 | 1 | R | -- | -- | Subtidal[3] | IWP | 0 |
| Limapontiidae | *Stiliger aureomarginatus* | 1 | 1 | 1 | R | R | -- | Subtidal | Western Pacific | 0 |
| Dendrodorididae | *Dendrodoris fumata* | 1-12 | 10 | 6 | C | U | -- | Subtidal | IWP | 0 |
| Dendrodorididae | *Dendrodoris denisoni* | 1 | 1 | 1 | R | R | -- | Subtidal | Indo Pacific | 0 |
| Dendrodorididae | *Dendrodoris nigra* | 1-5 | 3 | 3 | U | R | -- | Subtidal | IWP | 0 |
| Dendrodorididae | *Doriopsilla miniata* | 1-6 | 3 | 4 | U | R | -- | Subtidal | IWP | 0 |
| Dendrodorididae | *Doriopsilla carneola* | 1 | 4 | 7 | R | R | -- | Subtidal | Southern Aust. | 0 |
| Dorididae | *Discodoris lilacina* (*fragilis*) | 1-3 | 2 | 3 | R | R | -- | Unknown | Indian & Pacific | 0 |
| Dorididae | *Platyodoris galbannus* | 6-12 | 3 | 3 | U | R | -- | Unknown | SE Aust. | 0 |
| Dorididae | *Hoplodoris nodulosa* | 1 | 2 | 2 | R | R | -- | Subtidal | Southern Aust. | 0 |
| Dorididae | *Jorunna pantherina* | 1-3 | 4 | 5 | U | R | -- | Subtidal | Eastern Aust. | 0 |
| Dorididae | *Jorunna* sp. (purple) | 1 | 2 | 3 | R | R | -- | Subtidal | IWP | 0 |
| Dorididae | *Rostanga arbutus* (*bassia*) | 1-15 | 10 | 10 | C | U | -- | Unknown | NSW | 0 |
| Dorididae | *Thordisa* c.f. *villosa* | 2 | 1 | 1 | R | R | -- | Subtidal | IWP | 0 |
| Chromodorididae | *Ceratosoma amoena* | 1 | 3 | 3 | R | R | -- | Subtidal | Southern Aust., NZ | 0 |
| Chromodorididae | *Glossodoris atromarginata* | 1-2 | 2 | 2 | R | R | -- | Subtidal | Pacific & Indian | 0 |
| Chromodorididae | *Hypselodoris bennetti* | 1-6 | 10 | 5 | U | U | -- | Subtidal | SE Aust. | 0 |
| Chromodorididae | *Mexichromis mariei* | 1 | 1 | 1 | R | R | -- | Subtidal | West Pacific | 0 |
| Polyceridae | *Plocampherus imperialis* | 1 | 2 | 4 | R | R | -- | Subtidal | SE Aust. | 0 |
| Polyceridae | *Polycerid* sp. (unnamed sp.) | 1 | 1 | 1 | R | R | -- | Unknown | Unknown | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Goniodorididae | *Goniodoris* c.f. *meracula* | 25-32 | 4 | 3 | U | -- | -- | Unknown[3] | SE Aust. | 0 |
| Glaucidae | *Austraeolis ornata* | 1-2 | 5 | 8 | R | R | -- | Subtidal | Southern Aust. | 0 |
| Glaucidae | *Glaucus atlanticus* | 7-20 | 3 | 2 | R | -- | -- | Planktonic | Circumglobal | 0 |
| Glaucidae | *Glaucilla marginata* | 5-9 | 2 | 2 | R | -- | -- | Planktonic | Circumglobal | 0 |
| Glaucidae | *Spurilla australis* | 1 | 1 | 2 | R | R | -- | Subtidal | Southern Aust. | 0 |
| Aeolidiidae | *Aeolidiella foulisi* | 5-40 | 15 | 7 | C | C | -- | Unknown | Unknown | 0 |
| **CLASS: POLYPLACOPHORA** | | | | | | | | | | |
| Ischnochitonidae | *Callochiton crocina* | 1-6 | 2 | 2 | R | R | -- | Subtidal | WA-Qld, Tas, NZ | 0 |
| Ischnochitonidae | *Ischnochiton australis* | 2-200 | 85 | 13 | A | C | -- | Subtidal | Qld-Tas. | 0 |
| Ischnochitonidae | *Ischnochiton elongatus* | 4-200 | 80 | 12 | A | C | -- | Subtidal | NSW-WA, Tas. | 1 |
| Ischnochitonidae | *Ischnochiton versicolour* | 1-50 | 75 | 13 | A | C | -- | Subtidal | NSW-WA, Tas. | 1 |
| Chitonidae | *Sypharochiton pelliserpentis* | 30-200 | 100 | 13 | A | C | U | Intertidal | NSW-Tas. NZ | 4 |
| Chitonidae | *Onithochiton quercinus* | 1-30 | 10 | 13 | C | U | -- | Subtidal | Qld-NSW, WA | 4 |
| Chitonidae | *Rhyssoplax jugosus* | 1-10 | 10 | 11 | U | U | -- | Subtidal | NSW-Vic | 0 |
| Mopalidae | *Plaxiphora albida* | 5-25 | 35 | 12 | C | C | U | Intertidal | Qld-WA, Tas | 4 |
| Acanthochitonidae | *Crytoplax mystica* | 6-35 | 5 | 5 | U | U | -- | Subtidal | NSW | 0 |
| Acanthochitonidae | Unidentified sp. 1 | 2 | 1 | 1 | R | -- | -- | - | - | 0 |
| **CLASS: BIVALVIA** | | | | | | | | | | |
| Mytilidae | *Mytilus planulatus* | 5-40 | 3 | 2 | R | -- | -- | Subtidal[1] | NSW-WA, Tas | 2 |
| Mytilidae | *Brachidontes rostratus* | 35 | 2 | 1 | R | -- | R | Intertidal[4] | NSW-SA, Tas | 1 |
| Mytilidae | *Xenostrobus pulex* | 30-80 | 35 | 8 | C | C | U | Intertidal | NSW-WA, Tas | 0 |
| Mytilidae | *Trichomya hirsuta* | 5-50 | 55 | 7 | C | C | -- | Subtidal | NSW-Tas | 2 |
| Pteriidae | *Pinctada maculata* | 3-15 | 2 | 3 | R | -- | -- | Subtidal[1] | NSW-Torres St. | 0 |
| Anomiidae | *Anomia trigonopis* | 5 | 1 | 1 | R | -- | -- | Subtidal[1] | Qld-NSW | 0 |
| Limidae | *Limatula strangei* | 1-3 | 3 | 1 | R | R | -- | Subtidal | Qld-WA | 0 |
| Pectinidae | *Scaeochlamys livida* | 1 | 1 | 1 | R | -- | -- | Subtidal[1] | Qld-NSW | 1 |
| Galeommatidae | *Kellia* sp. | 1-16 | 10 | 9 | C | -- | -- | Subtidal | Qld-Vic | 1 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Lasaea australis* | 30-500 | 30 | 6 | C | U | -- | Subtidal | NSW-WA, Tas | 0 |
| Ostreidae | *Saccostrea glomerata* | 30-100 | 95 | 13 | A | C | U | Intertidal | Qld-Vic | 5 |
| Chamidae | *Chama* sp. | 1 | 1 | 1 | R | -- | -- | - | - | 0 |
| CLASS: CEPHALOPODA | | | | | | | | | | |
| Octopodidae | *Hapalochlaena maculosa* | 1 | 3 | 4 | R | -- | -- | Subtidal[5] | Qld-WA, Tas. | 0 |
| Octopodidae | *Octopus* c.f. *tetricus* | 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 camoflagued
[4] More common in sections of the coast sheltered from strong wave action
[5] Cryptic – hides and can be well camoflagued

## Figure Legends

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

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

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

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

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

*Table 2:* The number (percent) of species classified into four categories of rarity using three different measures; 1) Numerical (N) 2) Spatial (S); 3) Temporal (T). Regional indicates rarity assigned by any one of the three measures (see text). The number of species recorded in the same category using each combination of methods is also provided, along with the overall percent of species (% species) accounted for when the requirement to satisfy two or more definitions of rarity is applied.

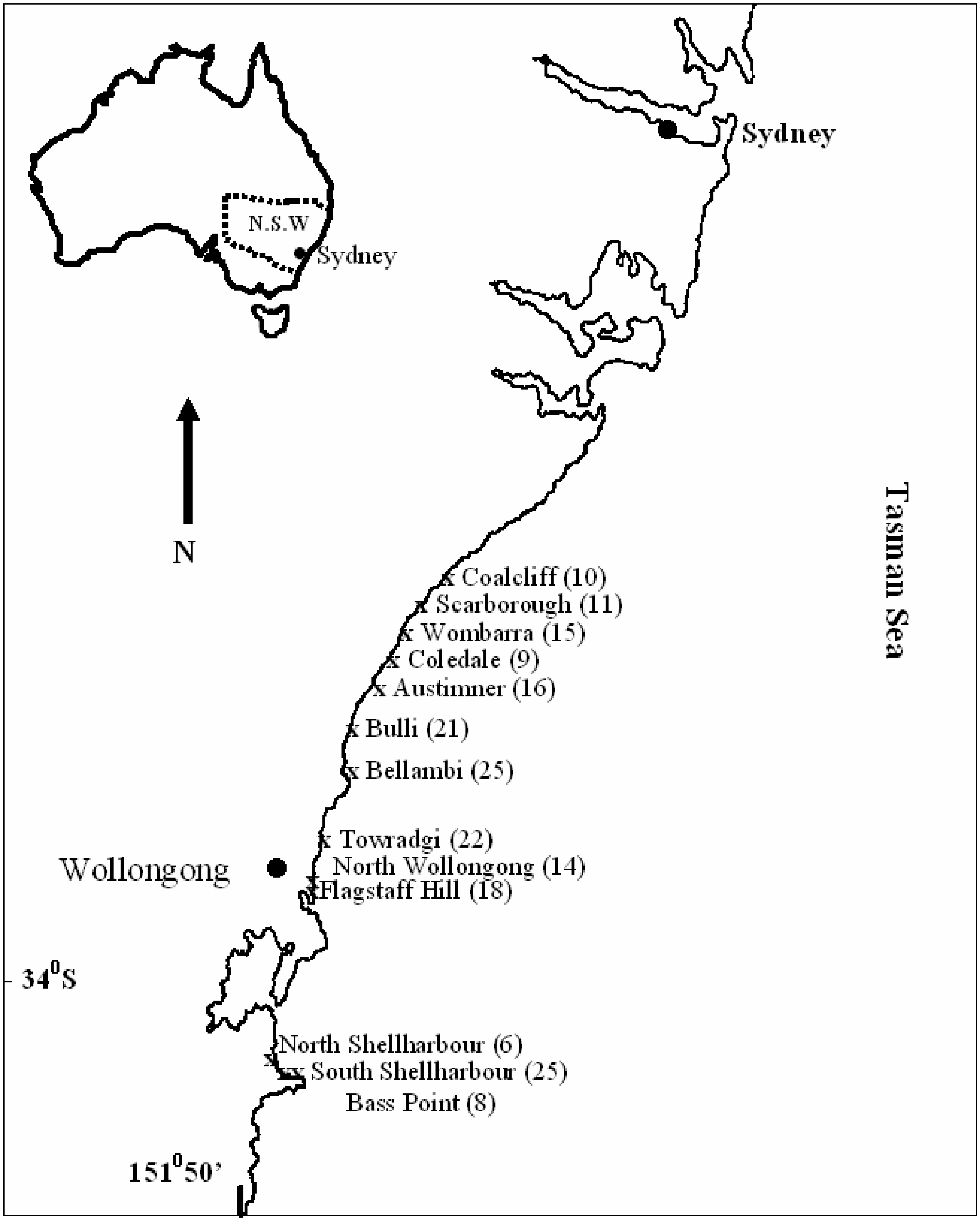
| **Measure of Rarity** | **Rare** | **Uncommon** | **Common** | **Abundant** | **% species** |
|---|---|---|---|---|---|
| Regional | 62 (42.5) | 33 (22.6) | 29 (19.9) | 22 (15.1) | 100 |
| N | 39 (26.7) | 40 (27.4) | 34 (23.3) | 33 (22.6) | 100 |
| S | 47 (32.2) | 28 (19.2) | 36 (24.7) | 35 (24) | 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 |

*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 vise 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 |

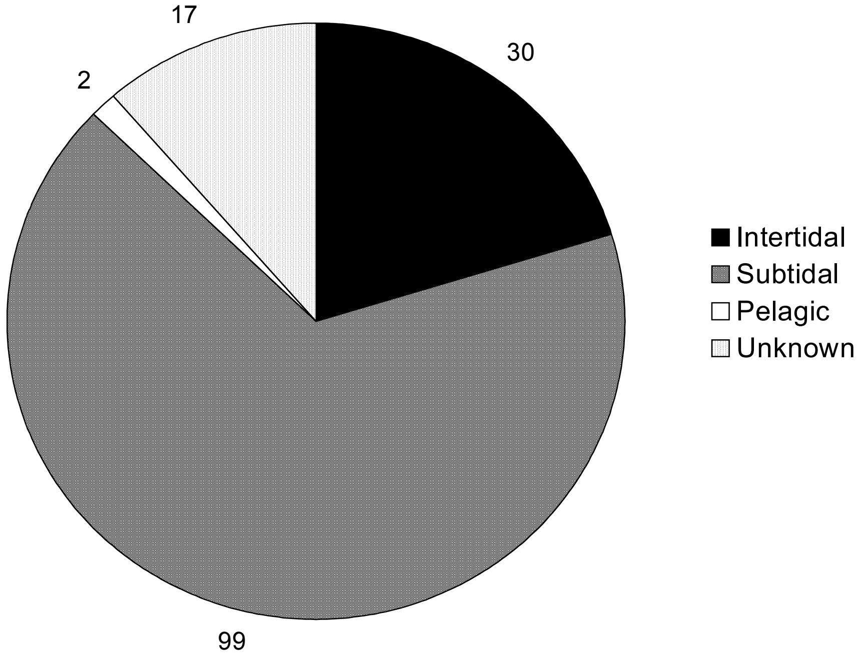
*Table 4*: The number of regionally rare, uncommon and common species of mollusc found along the Illawarra Coast from 1995-2000. The number of species in each of the categories have been separated according to whether they were or were not recorded in previous studies along the Illawarra Coast, N.S.W. Australia (refer to Owen, 1978; Tarrant, 1980; Miskiewicz, and Lock, 1991; MPR, 1992; MPR, 1995; Minchinton, 1996; Waters, 1997).

| **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 |

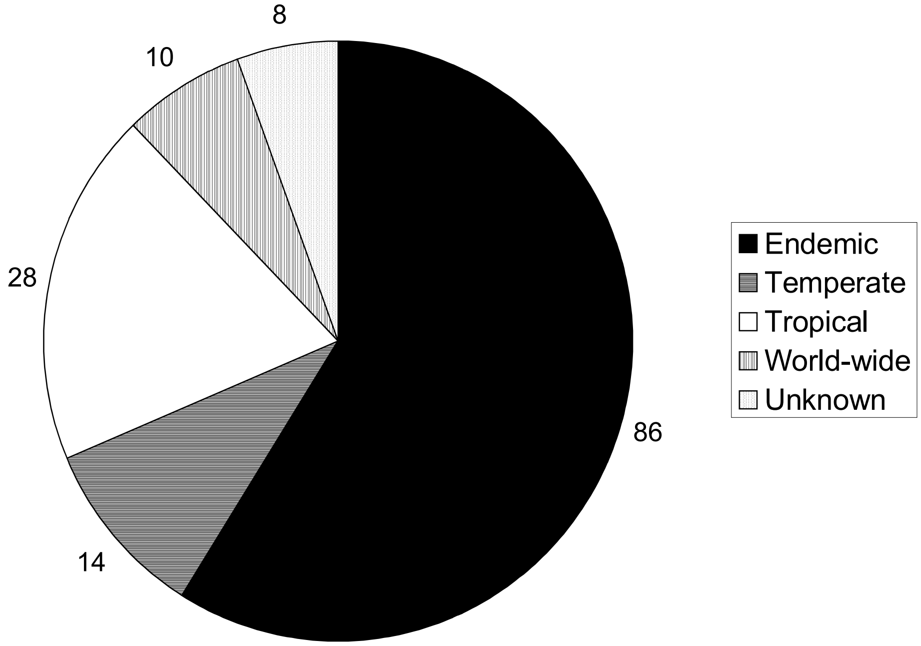


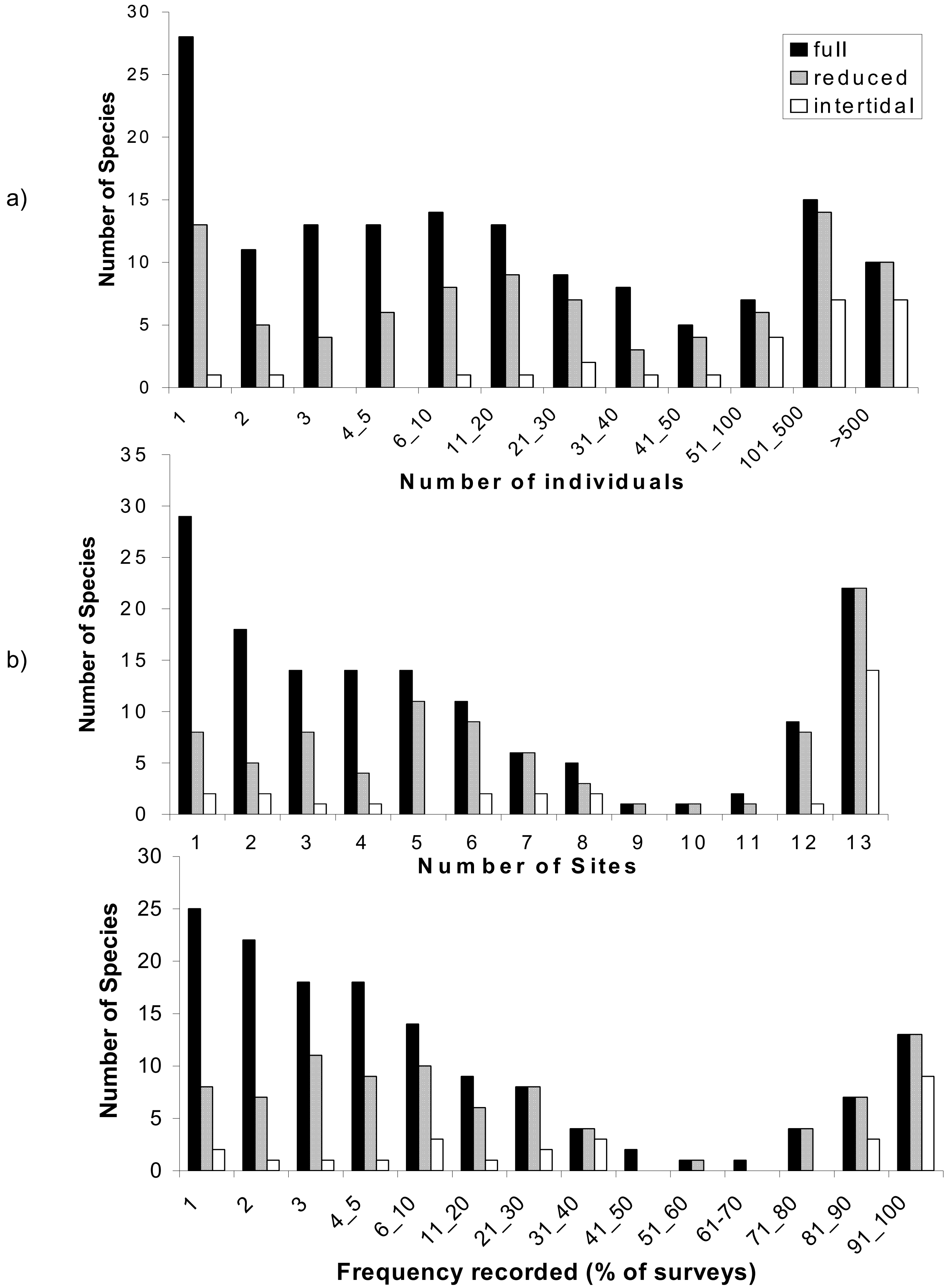
N.S.W
Sydney
Sydney
N
Tasman Sea
x Coalcliff (10)
x Scarborough (11)
x Wombarra (15)
x Coledale (9)
x Austinmer (16)
x Bulli (21)
x Bellambi (25)
x Towradgi (22)
Wollongong
x North Wollongong (14)
x Flagstaff Hill (18)
34⁰S
x North Shellharbour (6)
xx South Shellharbour (25)
Bass Point (8)
151⁰50'

a)

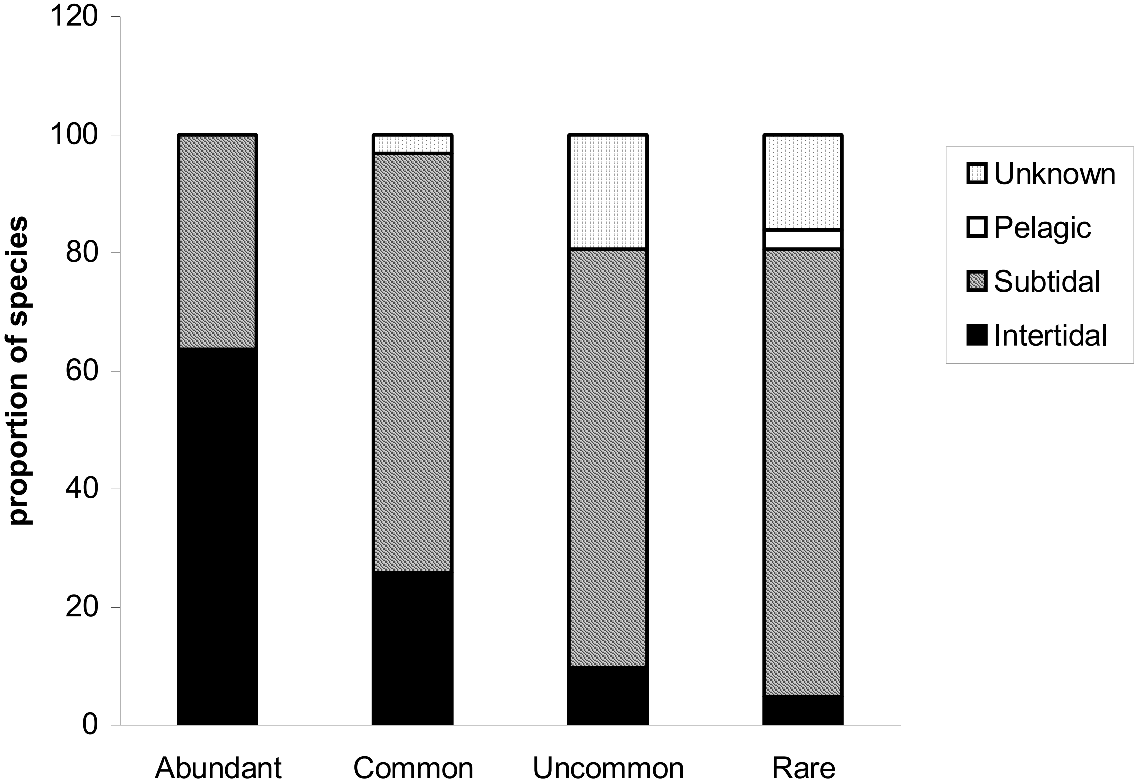

17
30
2
99
■ Intertidal
▨ Subtidal
☐ Pelagic
☐ Unknown

b)

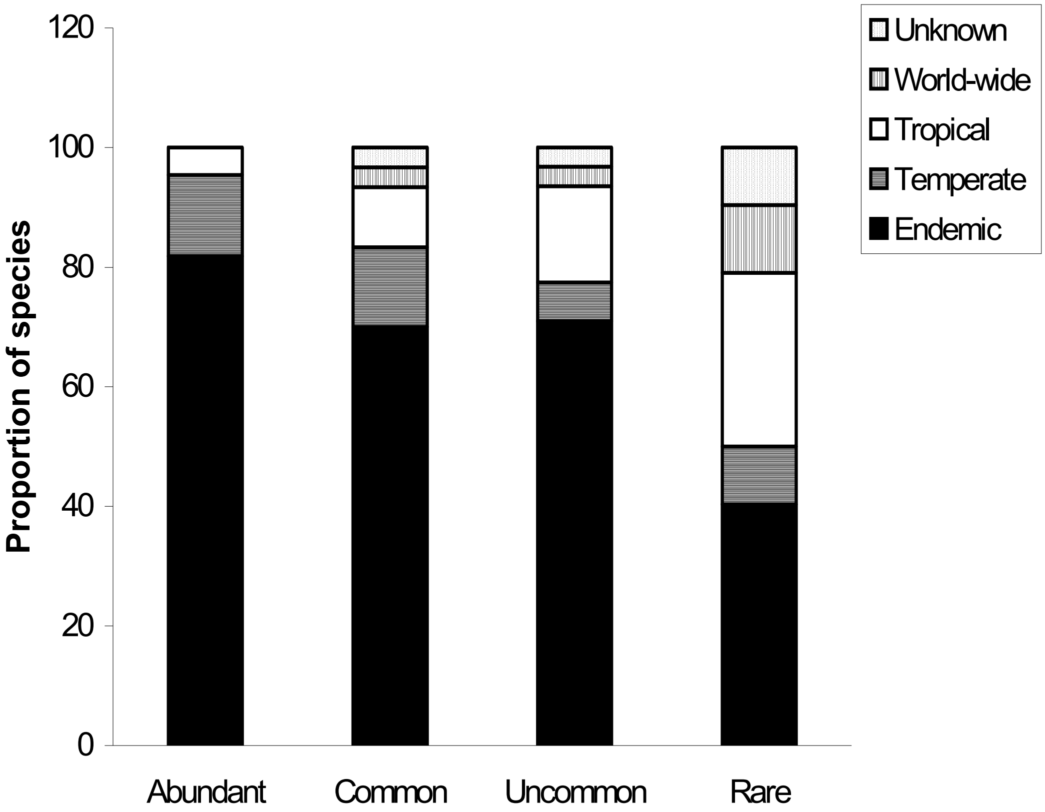

8
10
28
86
14
■ Endemic
▤ Temperate
☐ Tropical
▥ World-wide
☐ Unknown


a)
full
reduced
intertidal
Number of Species
30
25
20
15
10
5
0
1
2
3
4_5
6_10
11_20
21_30
31_40
41_50
51_100
101_500
>500
Number of individuals
b)
Number of Species
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Number of Sites
Number of Species
30
25
20
15
10
5
0
1
2
3
4_5
6_10
11_20
21_30
31_40
41_50
51_60
61-70
71_80
81_90
91_100
Frequency recorded (% of surveys)

a)


120
100
80
60
40
20
0
proportion of species
Abundant
Common
Uncommon
Rare
Unknown
Pelagic
Subtidal
Intertidal

b)


120
100
80
60
40
20
0
Proportion of species
Abundant
Common
Uncommon
Rare
Unknown
World-wide
Tropical
Temperate
Endemic