THE RAFFLES BULLETIN OF ZOOLOGY 2008 Supplement No. **18**: 259–264
Date of Publication: 15 Aug.2008

ASSESSMENT OF THREE TECHNIQUES FOR MEASURING THE BIODIVERSITY OF MOLLUSCS ON ROCKY INTERTIDAL SHORELINES IN EASTERN THAILAND

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ABSTRACT. – Three methods for comparing biodiversity of molluscs are compared on rocky intertidal shorelines near Kungkrabaen Bay, Thailand: timed visual searches, qualitative quadrats, and quantitative quadrats. Visual searches recorded the largest number of living species, 32.3 ± 2.5 (SE), significantly higher than in either the qualitative (26.5 ± 0.3) or quantitative (24.8 ± 1.0) quadrats. Including dead shells increased the mean number of species recorded per site in the visual searches to 60.8 ± 7.1. The numbers of species recorded by individual surveyors at the four sites varied considerably, with more experienced surveyors finding more species. It is concluded that a one-hour search is most cost effective. The type of information that is required should determine the method chosen. To determine total species diversity in an area, a visual search of living animals and dead shells should be made by an experienced surveyor. Qualitative or quantitative quadrats are most appropriate where the surveyors are volunteers with little experience in collecting molluscs. Quantitative studies can be used for other purposes such as analyzing trophic structure and species abundance.

KEYWORDS. – Protocol, Mollusca, marine, inventory, quantitative, qualitative, death assemblage.

INTRODUCTION

In recent years, biodiversity has been increasingly used as a tool for assessing many aspects of the environment. However, this immediately raises the question of which taxa to examine and how to make the measurements. Reaka-Kudla (1997) calculated that the known diversity on coral reefs is about 93,000 species of plants and animals, and estimated that there could be as many as ten times that in total. Clearly, with such a high biodiversity, including an unknown number of undescribed species distributed over dozens of plant and animal phyla, it is impossible to develop an inventory of total biodiversity in even a small area of the marine environment. Judgments must be made of which taxa to measure in a biodiversity study.

Molluscs dominate known biodiversity in the marine environment. Gosliner et al. (1996) estimated that molluscs comprise up to 60% of total biodiversity. Molluscs are essentially the insects of the sea. Squids, cuttlefish, octopus, bivalves, gastropods, chitons, and the worm-like aplacophorans are all molluscs. They occur in all marine habitats, from the upper intertidal to the depths of the oceans, in the water column itself, and geographically in polar, temperate, and tropical regions. Molluscs are found in a wide variety of habitat types and niches within each habitat, such as in or under sand and rocks, burrowed into rocks or wood, as parasites on other species, etc. Their ecology is also diverse. For example, various species are herbivores, carnivores, scavengers, filter feeders, some have single-celled algae (zooxanthellae) in their tissues that are primary producers, and others are parasitic. The great majority produce planktonic larvae that live in the water column for periods varying from a few days to over a year. Others produce young that emerge from the egg at a crawling stage. Some species are holoplanktonic. This taxonomic and biological diversity makes molluscs an attractive indicator group for biodiversity studies. Shells of large species are relatively easily identified through handbooks. For example, Wilson (1993–1994) has produced two volumes recording ca. 2,500 species of Australian prosobranch gastropods. The shell remains for a considerable period after the death of an individual as a record that it occurred in the area. Many become fossils and are permanent records. Nudibranchs, which lack a shell, can be identified through their colour patterns (Coleman, 2001).

If molluscs are chosen for use in biodiversity studies, the next question is: How do we measure their biodiversity? The most inclusive method is to collect all species in an area regardless of whether animal is living or is present only as a dead shell. Aside from shells that float, such *Sepia* and *Nautilus* shells, the presence of a dead shell is an indication that a species lives in an area. A second method is to conduct timed searches in an area. A third is to examine quantitative samples. All of these strategies have their strengths and weaknesses. The present study was undertaken to test the three strategies on intertidal rocky shores in the tropics. The methodology repeats that of Benkendorff (2003), allowing a comparison with her work on intertidal rocky shores in temperate eastern Australia.

MATERIALS AND METHODS

Four rocky shores were selected for the study based on their proximity to the Chantaburi Campus of Burapha University (Fig. 1): Laem Ban Tha Klaeng at the northern side of the entrance to Kungkrabaen Bay, Ao Kung Wiman (Hin Krong) further to the north, Laem Ban Kung Krabaen at the southern side of the entrance and Tung Chao Sadet Bay further south.

The study team consisted of five individuals with varying experience in conducting field studies on molluscs. At each station, each individual conducted three one-hour examinations of molluscan diversity: a timed search, qualitative quadrats and quantitative quadrats, as described by Benkendorff (2003). For the timed study, each person searched for molluscs on the shore based on his/her experience of where to search. All specimens > 5 mm in maximum shell measurement encountered alive were recorded. Dead shells were also noted on the basis that they probably occurred living on the shoreline. Shells of genera such as *Sepia,* which could have been readily washed in from elsewhere, were excluded from the analysis.

For the qualitative study, a 0.5 × 0.5 m quadrat was placed randomly on the shore and representatives of species occurring in each quadrat collected and recorded. The quadrats were spread over the full range of habitats present on the shore. The process was repeated as many times as possible during the hour. The strategy for the quantitative quadrats was identical except that the numbers of each species present were counted and recorded for every quadrat. Only living specimens were recorded for both the qualitative and quantitative quadrat studies. The order in which each survey type occurred was determined randomly. Statistical comparisons were undertaken with a Student's t-test.

To test whether one hour was an appropriate interval, a separate investigation was undertaken at Ao Kung Wiman. Four investigators visually searched the shore for two hours each and recorded the cumulative number of species recorded at every 15-minute interval.

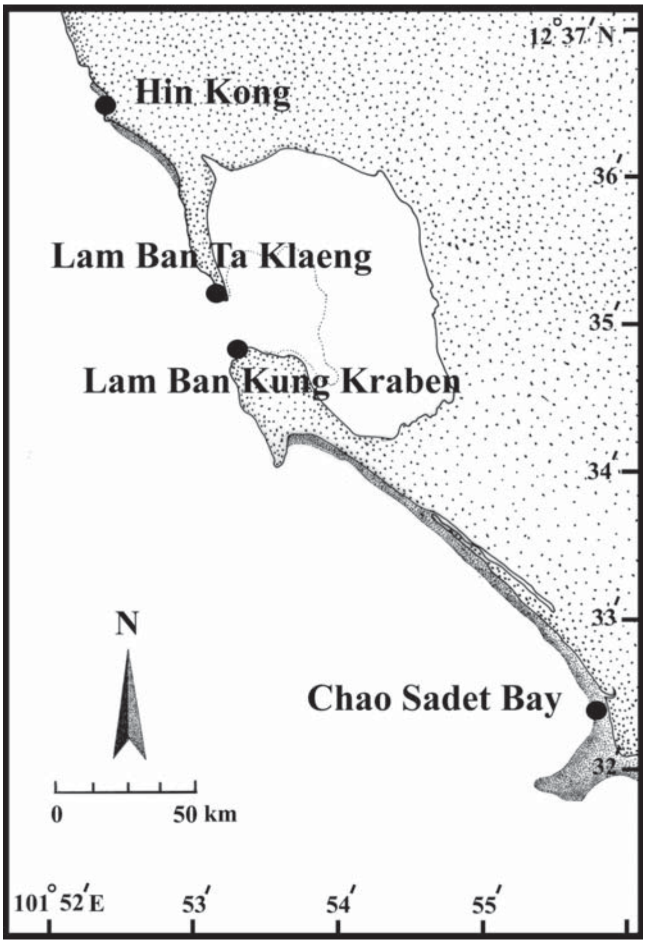

Fig. 1. Rocky shore sites used in this study in the vicinity of Kungkrabaen Bay.

Table 1. Numbers of species of molluscs recorded by different collecting techniques on rocky shores near Kungkrabaen Bay, Thailand.

	Site							
	Ao Kung Wiman		Lam Ban Tha Klaeng		Kungkrabaen		Tung Chao Sadet	
Sampling type	**N**	**Mean ± SE**	**N**	**Mean ± SE**	**N**	**Mean ± SE**	**N**	**Mean ± SE**
General - living	26	15.2 ± 1.2	32	16.6 ± 3.2	38	17.8 ± 1.2	33	18.5 ± 0.9
- dead	27	8.0 ± 2.2	19	9.4 ± 0.9	16	6.3 ± 1.3	52	19.3 ± 3.2
- total	53	27.4 ± 5.5	51	26.0 ± 3.1	54	24.2 ± 2.2	85	37.8 ± 3.4
Qualitative species recorded	27	21.4 ± 4.8	26	11.2 ± 2.1	26	14.0 ± 2.5	27	16.3 ± 0.6
Qualitative quadrats examined	114	19.0 ± 2.2	95	19.0 ± 6.5	64	10.7 ± 1.9	93	18.8 ± 2.0
Quantitative species recorded	22	14.0 ± 1.6	27	13.8 ± 1.8	25	11.0 ± 1.2	25	14.8 ± 0.9
Quantitative quadrats examined	70	11.7 ± 0.8	77	15.4 ± 5.3	52	9.7 ± 1.5	74	13.2 ± 1.7

Table 2. Numbers of species of molluscs recorded by different collecting techniques by six individual surveyors on rocky shores near Kungkrabaen Bay, Thailand.

Surveyor	**General survey (mean ± SE)**	**Qualitative quadrats (mean ± SE)**	**Quantitative quadrats (mean ± SE)**
1	32.5 ± 4.1	13.3 ± 1.4	13.8 ± 0.9
2	21.7 ± 4.0	12.0 ± 1.8	9.7 ± 1.9
3	21.5 ± 3.0	14.5 ± 2.6	14.3 ± 1.1
4	33.5 ± 4.6	13.8 ± 1.2	14.3 ± 1.0
5	25.3 ± 4.6	12.5 ± 1.9	13.5 ± 1.8
6	29.3 ± 4.9	14.8 ± 1.5	14.8 ± 1.4
Mean	27.3 ± 2.1	13.5 ± 0.4	13.4 ± 0.8

RESULTS

In all, 119 species of molluscs were recorded during a total of 80 hours at the four sites. The largest numbers of species were recorded by the visual searches, ranging from 51 at Lam Ban Tha Klaeng to 85 at Tung Chao Sadet, including dead shells (Table 1). If only the live-recorded shells are considered, the range was from 26 at Ao Kung Wiman to 38 at Kungkrabaen. The mean number of living species recorded per site in the visual searches was 32.3 ± 2.5 (SE), significantly higher than in either the qualitative (26.5 ± 0.3) or quantitative (24.8 ± 1.0) collections (t-test, $p < 0.05$). In fact, all visual searches recorded more species than either the qualitative or quantitative searches except at Ao Kung Wiman, where 27 species were recorded in the qualitative quadrats and only 26 species were found in the visual searches. The visual search of this site was the first study undertaken during the survey program, and it could be that parties were adjusting their visual search images. Including dead recorded shells significantly (t-test, $p < 0.05$) increased the mean number of species recorded per site by 88% from 32.3 ± 2.5 to 60.8 ± 7.1. All sites had substantial numbers of dead species that were not found alive, but most of the dead species were recorded alive in one of the three other sites examined during the study.

There were no significant differences (t-test, $p > 0.05$) between the mean number of species recorded alive in the qualitative (26.5 ± 0.3) and quantitative quadrats (24.8 ± 1.0) (Table 1). Whereas the number of species recorded was similar, the increased time required to count specimens decreased the mean number of quadrats investigated from 91.5 ± 10.3 in the qualitative quadrats to 68.3 ± 5.6 in the quantitative surveys.

There was considerable variation in the mean number of species recorded by individual surveyors at the four sites (Table 2), with means varying from 21.5 ± 3.0 to 32.5 ± 4.1. However, there was considerable variation between sites, with three different individuals collecting the most species at a given site. The range for qualitative quadrats was greater, from 9.7 ± 1.9 to 14.8 ± 1.4.

A total of 71 species was recorded during the two-hour timed survey at Ao Kung Wiman (Table 3), with a mean of 45.5 ± 3.7 species recorded by each individual. Recording was rapid in the first 15 minutes, with 33 species recorded at a mean of 21.0 ± 2.7 per individual. The collecting rate declined substantially after this. After one hour, 58 species had been recorded with a mean of 39.8 ± 2.9 per individual. Doubling the collecting effort to two hours increased the total number of species to only 71 (an increase of 13) and the mean per surveyor by 5.7 ± 0.9.

DISCUSSION

The primary conclusion of this study is that the method

Table 3. Numbers of species recorded by four surveyors at 15-minute intervals at Ao Kung Wiman, Thailand.

15-min time interval	Total species recorded	Mean ± SE
1	33	21.0 ± 2.7
2	13	8.5 ± 1.0
3	12	6.5 ± 0.9
4	6	3.8 ± 0.6
5	1	1.3 ± 1.5
6	3	2.0 ± 0.4
7	3	2.3 ± 0.5
8	0	0.3 ± 0.3
Total	71	45.5 ± 3.7

used to measure biodiversity should be determined by the information required. If the goal is to determine the total number of species in an area, then a visual search in all of the available habitats, including both living animals and dead shells, should be made by an experienced surveyor. As would be expected, more experienced surveyors found more species, but there was considerable variation between individuals. The time spent at each locality was also important, but it was concluded that a one-hour search period was the most effective. However, it should also be noted that the searches must be done at low tide. If stations are some distance apart, it would be possible to do only one locality at a given low tide, so additional time can be devoted to the site. On the other hand, it could be important to collect for a standard period of time with a single combination of surveyor(s) to ensure that data are comparable between sites.

These results compare well with those of Benkendorff & Davis (2002) who worked on intertidal rock platforms on the eastern coast of Australia. They also used standardized search techniques, in which 13 reefs were studied on multiple occasions. Individual reefs were searched for four hours at a time. One hundred and seventy-two surveys were conducted over a three-year period. There was a strong positive correlation between total diversity as measured by the overall accumulation of species at a site from multiple surveys and the results of a single survey. A critical feature was that the total diversity at a site was not correlated with the number of surveys. In other words, greater diversity at a site was not simply a result of more searches being conducted. In a follow-up study, Benkendorff (2003) concluded that a one-hour search was sufficient to provide a representative measure of molluscan species richness. As in the present study, she found that using quantitative quadrats reduced the amount of area that could be searched, but it also changed the relative rankings of the various sites.

Repeated searches in a variety of habitats can be used to provide estimates of biodiversity of molluscs in various geographic areas as the information is accumulated over a large number of sites. Such surveys have been undertaken in a variety of localities in the Indo-Pacific to determine the biodiversity of molluscs, fish, corals, and other groups (Wells & Allen, 2004). The basic sampling strategy was similar to the methods used in the present study. A wide range of intertidal or subtidal sites in the study area were each examined in short, intensive surveys that ranged from seven to twenty days. Although the results were not statistically comparable, they provided a range of benefits. Notably, there was a wide range of specimens in the Western Australian Museum (WAM) surveys, which were deposited in the WAM. These provide verifiable records of new taxa, range extensions, etc. For example, specimens recorded on three expeditions to the offshore atolls of the Western Australian NorthWest Shelf were almost all range extensions because the atolls had never been systematically surveyed. Not only were new taxa discovered, but overall 20–25% of the species recorded were new records for Western Australia or even Australia (Berry, 1986, 1993). The taxonomic composition of the offshore molluscs was closer to that of the Great Barrier Reef than to the nearby Western Australian continental coastline (Wells, 1986). Surveys of this type can be enhanced by conducting parallel studies of reef morphology, fishing pressure, etc.

Whereas the number of collecting days varies, the work provides relative estimates of biodiversity in different areas. In general, localities close to the centre of coral reef biodiversity in the area of Philippines-Malaysia-Indonesia had more species than sites away from the centre. Five surveys in the Philippines, Indonesia, and Papua New Guinea recorded 541–665 species. Localities away from the centre or those with restricted habitats tended to have fewer species. In particular, Christmas Island, which is only 150 km south of the Indonesian island of Java but has low habitat diversity, had only 313 species recorded on the survey.

Clearly, not all of the species present in an area will be recorded in a short survey undertaken by a single person. For example, as part of the Conservation International program, Wells (1998) and Wells & Kinch (2003) conducted two surveys of Milne Bay, Papua New Guinea: the first survey was for 19 days and recorded 638 species, and the second was for 11 days and recorded 643 species. Combined, the two surveys found a total of 945 species. In another example, a 20-day rapid assessment of molluscan biodiversity at the Cocos (Keeling) Islands in the Indian Ocean recorded 380 species of molluscs (Wells, 1994). However, if species found in the earlier surveys by Abbott (1950) and Maes (1967) are added, a total of 610 species are known from the atoll. In a more comprehensive example, Bieler & Mikkelsen (2004) and Mikkelsen & Bieler (2004) developed a list of the marine bivalve molluscs of the Florida Keys based on 10 years of collecting, and a critical review of both museum specimens and literature data. They developed a database of 12,382 records representing 389 species. This was a 139% increase on the known bivalve fauna of the area compared to a 1995 survey, in an area that is relatively well known and has a low biological diversity compared to Indo-West Pacific localities. Forty-two percent of the species were based on specimens recorded only as dead shells; 12.5% were recorded as singletons or doubletons. They attributed these features to the fact that many molluscs are cryptic, burrowing, or parasitic species that are rarely found alive. In fact, many species were known only from dead shells. The extreme example of intensive surveys is represented by Bouchet et al. (2002), who in 400 collecting days in New Caledonia recorded diversity of about 3,000 species; 28.5% were not encountered alive and 20% were singletons.

The use of dead shells is an issue in molluscan biodiversity studies. Ignoring the high proportion of dead shells at a locality risks substantially underestimating the total molluscan biodiversity. In the present study, using the presence of dead shells at a station increased the mean number of species recorded in visual searches from 32.3 ± 2.5 to 60.8 ± 7.1. Most of the additional species were recorded alive at one or more of the other stations, or in fact by another surveyor at the same station, confirming that they live locally. Kidwell (2001, 2002) examined the problems encountered in using dead shells. Notably, the mixture might change over time. Kidwell (2001) found that dead assemblages have the same relative rankings of species as those found alive in a single sample. The relationship is maintained or improved as further live-sampling is undertaken.

Geological age is an issue where there can be inadvertent mixing of strata during collection, or where Recent species have been kept in situ – in the habitat but no longer occurring alive in the area. For example, the bivalve genus *Katelysia* is abundant as a subfossil in estuaries on the western coast of Western Australia, but no longer occurs living in the region (Brearley, 2005). Bouchet et al. (2002), Kidwell (2001, 2002), Bieler & Mikkelsen (2004), and Mikkelsen & Bieler (2004) all concluded that dead shells should be included in molluscan biodiversity studies. Bieler & Mikkelsen (2004) examined the effect of using dead shells by conducting a rapid assessment (RAP) of bivalves at Looe Key in the Florida Keys. Detailed data recorded for the area showed there were 104 species known. Sixty-two were found in the RAP study, or 60% of the total recorded, based on both living and dead shells; they considered this to be an effective survey. If only live-collected shells were included, only 20 species (19%) were found and the survey was considered ineffective.

Bieler & Mikkelsen (2004) concluded that at least two approaches are required to determine how closely a survey comes to obtaining all available species. One approach is to examine the number of singletons or doubletons in the collection. Working with spiders, Coddington et al. (1996) argued that the number should decrease as collecting increases the proportion of low recordings. Bieler & Mikkelsen (2004) countered that collecting molluscan shells tends to increase the number of species over time. Species accumulation curves can be used to determine whether most "possible" species have been recorded. This has been used successfully for spiders (Colwell & Coddington, 1994) where there was a standardized collecting effort in reasonably homogenous areas, but Bieler & Mikkelsen (2004) argued that this technique does not apply to molluscan assemblages in area such as the Florida Keys where there is considerable range of habitats. Species accumulation also reflects changes in effort over time. However, it can be useful because we know the total number of species of bivalves in the Florida Keys as a result of 160 years of collecting. Data such as these can be used to determine loss/gain of species over time.

In contrast to the results obtained in the visual searches, the difference between living animals recorded in the qualitative (26.5 ± 0.3) and quantitative (24.8 ± 1.0) collections was statistically insignificant. Whereas the number of species recorded was similar, the increased time required to count specimens decreased the mean number of quadrats investigated from 91.5 ± 10.3 in the qualitative quadrats to 68.3 ± 5.6 in the quantitative surveys. There was relatively little difference in either dataset between experienced and inexperienced surveyors. These results suggest that if the goal of the study is to provide statistically replicable results using a range of surveyors, such as volunteers, a series of a standard number of quantitative quadrats at each station would be the best approach. Again, approximating the number of quadrats that could be investigated in an hour would provide a good result. Once these data are obtained, they can be manipulated for a variety of purposes, such as determining the taxonomic composition by groups at differing levels, community structure, and trophic relationships.

ACKNOWLEDGMENTS

The International Marine Bivalve Workshop (with contributions from other molluscan groups) in Chantaburi, Thailand, was organized by Kashane Chalermwat (Burapha University), Fred Wells (Western Australian Department of Fisheries), Rüdiger Bieler (Field Museum of Natural History, Chicago) and Paula M. Mikkelsen (American Museum of Natural History), and supported by U. S. National Science foundation grant PEET DEB-9978119 (to RB and PM). Field transportation in Thailand and chemicals were provided by the Faculty of Science, Burapha University. We also thank Dr. Suchart Upatham, President, and Dr. Pichai Sonchaeng, Director of the Institute of Marine Sciences, both of Burapha University, who strongly supported the workshop. Without their support it could not have happened. In addition, we thank our colleagues at the workshop and staff of the Burapha University, Chantaburi Campus, for making the workshop such a success and so enjoyable.

THAI ABSTRACT

คณะผู้วิจัยได้ทำการเปรียบเทียบความหลากหลายทางชีวภาพของหอยบริเวณหาดหินในเขตน้ำขึ้นน้ำลงโดยใช้วิธีการประเมิน 3 รูปแบบบริเวณโดยรอบอ่าวคุ้งกระเบนได้แก่การจับเวลาและสำรวจด้วยสายตา การใช้ quadrat สุ่มเชิงคุณภาพ และการใช้ quadrat สุ่มเชิงปริมาณ การสำรวจด้วยสายตาได้จำนวนหอยมีชีวิตสูงสุดคือ 32.3±2.5 (SE) ซึ่งสูงกว่าการสุ่มเชิงคุณภาพ (26.5±0.3) และเชิงปริมาณ (24.8±1.0) การรวมเปลือกหอยที่ตายแล้วทำให้จำนวนหอยทั้งหมดที่พบเพิ่มขึ้นในแต่ละสถานที่ โดยจำนวนหอยจากการสำรวจด้วยสายตาเพิ่มเป็น 60.8±7.1 ชนิด จำนวนชนิดของหอยที่ค้นพบโดยผู้วิจัยแต่ละคนในสถานที่เก็บตัวอย่างทั้ง 4 แห่งแตกต่างกัน โดยผู้สำรวจที่มีประสบการณ์มากกว่าจะพบหอยมากชนิดกว่า เราขอสรุปว่าการสำรวจเป็นระยะเวลา 1 ชั่วโมง เป็นการใช้เวลาอย่างเหมาะสมที่สุด ผู้วิจัยควรเลือกวิธีสุ่มให้เหมาะสมกับข้อมูลที่ต้องการ ในการศึกษาความหลากหลายสูงสุดในแต่ละพื้นที่ ผู้วิจัยควรใช้วิธีสำรวจด้วยสายตา (ทั้งหอยมีชีวิต และเปลือกหอย) โดยผู้ทำการสำรวจควรเป็นผู้มีประสบการณ์ การสุ่มเชิงคุณภาพและเชิงปริมาณเหมาะสมกับสถานการที่ผู้สำรวจเป็นอาศาสมัครที่มีประสบการณ์ในการเก็บตัวอย่างหอยไม่มาก การสำรวจเชิงปริมาณสามารถใช้ในการวิเคราะห์โครงสร้างและลำดับขั้นในการกินรวมทั้งจำนวนชนิด

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