Potential conservation benefits and problems associated with bioprospecting in the marine environment

Kirsten Benkendorff

Department of Biological Sciences and Department of Chemistry,

University of Wollongong, NSW, 2522, Australia

Email: kirsten@uow.edu.au

ABSTRACT

Chemical prospecting for pharmaceuticals in natural organisms (bioprospecting) has been both championed as a tool for conservation and criticised for not being environmentally sustainable. However, there has been little attempt to address the ways that bioprospecting could contribute to conservation if undertaken in an ecologically sustainable manner. Bioprospecting can provide financial benefits, but these are unlikely to advance natural resource management unless contractual agreements granting access to biodiversity specify that a percent of the fees and royalties must be used to fund conservation projects. A more likely positive outcome for conservation is that bioprospecting provides funding opportunities for the rapid documentation of biological diversity. If representative specimens of each sampled taxa are lodged in accredited institutes, a useful resource will be available for other research projects. Bioprospectors can also emphasize the need for conservation by increasing the community's appreciation for marine biodiversity. Nevertheless, bioprospecting will only be compatible with conservation objectives if it can be shown to have no negative impacts on the environment. There is some evidence that marine organisms have been over-collected for natural products research, although it is currently difficult to assess the impacts of marine bioprospecting due to the fact that the sample quantity and abundance of the target organism are rarely published in the scientific literature. It is apparent that research on the natural history and ecology of target organisms needs to be assigned greater priority. Bioprospecting could be undertaken with minimal impact on abundant species with broad geographic distributions because modern technologies permit the preliminary identification of bioactive compounds from small samples (<100g). However, environmental impact assessment may be necessary for the recollection of organisms prior to complete chemical characterisation and pharmacological evaluation. Once a useful compound has been identified several options are available for large-scale production, including chemical synthesis and aquaculture. By adopting a precautionary approach, new marine bioresources could be developed in a sustainable manner. Consequently, bioprospecting does have potential to contribute biodiversity research and the conservation of natural resources.

Introduction

Continued pressure on the environment from technological progress and human population growth has made it necessary to place a commodity value on biodiversity (Randall 1991). The provision of unprecedented biologically active compounds is one value of biodiversity that has been widely recognised (Eisner 1990; Wilson 1994; Beattie 1994). The majority of the drugs currently in commercial use and those being developed are of natural origin (Cragg *et al.* 1997a). As stated by Eisner (1990): "In a very real sense, and quite aside from other measures of worth, species have chemical value".

Pages 90 - 100 in *A Zoological Revolution. Using native fauna to assist in its own survival.* Edited by Daniel Lunney and Chris Dickman, 2002. Royal Zoological Society of New South Wales, Mosman 2088 and Australian Museum.

Over the last decade there has been a resurgence of interest in the investigation of natural products as a source of new pharmaceutical agents (Beattie 1993; Cragg *et al.* 1997a). This has been sparked by growing problems such as the evolution of resistance to antibiotics, the increased occurrence of some diseases (e.g. tuberculosis) and the appearance of new diseases (e.g. HIV AIDS). Coupled with this is the alarming rate of species extinction and the continuing threat to biodiversity, which could lead not only to biotic impoverishment, but also to chemical impoverishment (Eisner 1990). In recognition of these factors, the International Society of Chemical Ecology developed the Göteborg Resolution, which called for an increased effort to expand the search for new natural products (Eisner and Meinwald 1989). Ultimately, bioprospecting has been engaged as a means for discovering new medicines, an instrument for sustainable economic development and an incentive for conservation (Asebey and Kempenaar 1995).

Conservation Incentives

Financial benefits

It has been suggested that the imperative to find novel natural chemicals before they disappear has made bioprospecting a politically respectable and fundable tool for conservation (Tangley 1996). In a revolutionary proposal, the International Society of Chemical Ecology suggested the financial coupling of chemical prospecting with conservation programs (Eisner and Meinwald 1989). The first of these so-called "dollars for diversity" schemes was an agreement between Costa Rica's National Institute of Biodiversity (InBio) and the pharmaceutical company Merck. Merck negotiated an up front fee of $1 million for the opportunity to explore Costa Rica's biodiversity for novel drugs (Roberts 1992). A number of critics have accused InBio of selling off the nations resources too cheaply. However, if a useful new drug is discovered Merck will also pay InBio a share of the royalties. An important feature of the Merck-InBio deal is that 10% of the up front fee and 50% of the royalties must go directly towards conservation (Roberts 1992). InBio have turned over the first installment of Merck's up front fee to the Ministry of Natural Resources to support a marine park at Coco Island. The Merck-Inbio agreement serves as one model for other species-rich nations interested in creating sustainable alternatives for economic development.

A number of other biodiverse nations have subsequently negotiated agreements with pharmaceutical companies for access to their biological resources (e.g. Roberts 1992; Sittenfeld and Villers 1993; Tangley 1996; Aalbersberg 1997). These agreements typically involve financial benefits to the sovereign nation, although there are no specific requirements for these benefits to be channelled towards conservation. There is simply an assumption that the market in bioprospecting will provide an incentive to preserve areas for conservation and non-destructive uses. However, this assumption has been recently called into question because the chances of a profitable discovery are quite low (Farrier and Tucker, 2001) and the benefits of voluntary conservation are unlikely to be transferred to the local landholders and users (Barrett and Lybbert, 2000). To address this problem the Commonwealth inquiry into access to Australia's biological resources has recommended that bioprospecting contracts should include the requirement that some benefits, whether monetary or non-monetary, should promote biodiversity conservation in the area covered by the contract (Voumard, 2000). A further recommendation was to consider allocating a percentage of any monetary benefits to a fund for environmental purposes (Voumard, 2000). Bioprospecting agreements will probably have limited use as tools for conservation unless some of the financial benefits are channelled into specific conservation projects.

Biodiversity Research

Bioprospecting can also contribute to conservation indirectly by financing biodiversity research. The Queensland Government suggested that the discovery and documentation of Australia's biodiversity has been significantly enhanced by bioprospecting, particularly for some marine invertebrate phyla (Voumard, 2000). World-wide estimates of sponge diversity are said to have tripled as a consequence of bioprospecting (Farrier and Tucker, 2001). Peter Murphy from the Australian Institute for

Marine Science comments that their biodiscovery program has lead to the acquisition of extensive biogeographical information and support for taxonomic studies on invertebrates (Farrier and Tucker, 2001). In Costa Rica, InBio has trained more than 30 parataxonomists to sort biological samples into coarse taxonomic units, which can be subsequently identified by professional taxonomists (Roberts 1992). A major component of conservation effort involves cataloguing biological resources, so any financial support for this work provides conservation benefits. These outcomes are not currently mandatory in bioprospecting agreements, although the International Union of Pure and Applied Chemistry recommends that bioprospectors provide support for surveys and inventories of existing fauna (Andrews *et al.* 1996a). Chemical screening itself can also be considered a useful form of inventory (Eisner 1990) as it contributes to our knowledge of molecular diversity and chemical evolution.

An example of the way bioprospecting can trigger biodiversity research is provided by my own research on intertidal molluscs along the Illawarra coast, NSW, Australia. I sampled molluscan egg masses to test the hypothesis that they contain novel antibiotics. However, there was little information available on the diversity or conservation status of marine molluscs in this region. Consequently, it was necessary to conduct surveys on the distribution and abundance of local species to reduce the potential impacts of sampling. Over a period of three years I repeatedly surveyed 13 intertidal reefs in the region, during which over 160 species and 50 egg masses were recorded. Only 31% of the molluscs identified in this study had been previously recorded on the Illawarra Coast (Benkendorff 1999a). An important breeding site and hotspot of molluscan species richness was also identified. This information has been used by the local council to develop a marine management plan (Benkendorff 1999b) and discussions are currently underway with the NSW Fisheries Department to locate a marine reserve in this area (Mr Phil Woodcock, Shellharbour City Council, pers. comm.).

The search for new chemicals may also lead to the discovery of new species or rare species in new locations. For example, Garson (1996) discovered a new species of flatworm while collecting specimens for natural products research on the Great Barrier Reef. In my study of intertidal molluscs I recorded new distributions for one southern Australian seaslug and two tropical snails, as well as observing an undescribed polycerid nudibranch (Benkendorff 1999a). The Code of Ethics in the *Manila Declaration* (1992) suggests that foreign collectors of biological samples should "inform the host institute (or) appropriate organisation of new localities of rare (or) endangered species found". Any information on rare and endangered or potentially new species should be provided by bioprospectors, whether working overseas or in their own country.

The *Manila Declaration* (1992) also recommends that the regulations for bioprospectors should ensure that "adequately annotated, preserved voucher specimens of biological material are lodged in appropriate national institutions". A similar recommendation was made in the Commonwealth Inquiry into access to biological resources (Voumard, 2000). Permanent reference collections are important for the purpose of taxonomic identification. They can also provide a useful data base for biodiversity assessment and a range of other research programs (e.g. Ponder 1999). By making their collection data available to the scientific community, bioprospectors can contribute to the documentation of biological diversity at a reduced cost to governments.

Community awareness and appreciation

Chemical prospecting can help to raise community awareness about the need for conserving biodiversity and acts to raise the profile of organisms that may otherwise be considered insignificant or even undesirable. Wilson (1993), points out that there are two main things that are required for effective conservation; knowledge and political will. Species of medicinal value are specifically listed as important for biodiversity and bioresource management in the international *Convention on Biological Diversity* (1992, Annex 1) and the *National Strategy for the Conservation of Australia's Biological*

Diversity (1997, Objective 1.1). This suggests that Governments are beginning to appreciate the utilitarian value of biodiversity. Ultimately however, the political will necessary for appropriate environmental management stems from a well-informed and environmentally conscious community (Wilson 1993).

Bioprospectors have the opportunity to communicate directly with the public during field trips. While collecting samples on the Illawarra Coast, I have alerted members of the local community to conservation issues, including Fisheries bag limits and the protected status of octopus on rock platforms in NSW. Many people appear to be ignorant of the existing legislation, while others may be more willing to comply after these regulations have been personally explained, in terms of the long-term sustainability of recreational fishing. This indicates the need for local education campaigns to reach members of the community. Given the limited resources available to most government departments, bioprospectors and other field researchers could play a role as voluntary education officers, as they often have a good understanding of the natural communities they work on.

One of the best mechanisms for spreading a message to the general public is through the media. However, it is currently difficult to generate media enthusiasm to push the case for the conservation of invertebrates (Smith 1999). Nevertheless, my experience indicates that the media are interested in stories involving the potential medicinal value of marine invertebrates. During the last three years I have conducted over 20 media interviews regarding the antibiotic properties of marine molluscs. In nearly all of these stories the journalists have willingly promoted the need for conservation. Ultimately, this type of media coverage could act to educate the public about the value of organisms such as "slugs and snails".

The problems with bioprospecting

Ethical issues

The Australian Science, Technology and Engineering Council (1998) have outlined a number of ethical issues surrounding chemical prospecting in the natural environment. Firstly, the collection of material for chemical and pharmacological studies is an extractive process and therefore could lead to environmental impacts. Secondly, the custodians of natural resources are stakeholders in the potential benefits arising from the commercial development of a natural product. There should be fair and equitable sharing of the results and benefits stemming from the utilisation and commercialisation of natural resources. Thirdly, intellectual property rights must be protected when traditional or other knowledge about the natural biota is shared with bioprospectors.

The ethical issues associated with bioprospecting have been addressed to some extent in several declarations, resolutions and other publications (e.g. *The Convention on Biological Diversity* 1992; *The Manila Declaration* 1992; *The Melaka Accord* 1994; Commonwealth Government 1994; Andrews *et al.* 1996a,b; Cragg *et al.* 1997b; Common-wealth-State Working Group on Access to Australia's Biological Resources 1997). These have been developed primarily to 1) facilitate access to biological resources, 2) ensure equitable benefit and 3) protect the traditional knowledge of indigenous people. There has been comparatively little attention given to the potential environmental impacts of bioprospecting.

Evidence of unsustainable bioprospecting

There has been considerable concern that species have been exploited for pharmaceutical research in the ocean with little regard to the potential impacts on their populations (Garson 1996, 1997; Anderson 1995). These concerns appear to be justified when some of the literature on marine natural products is examined. For example, in order to obtain 28mg of an anticancer peptide Dolastatin 10, Pettit *et al.* (1987) extracted 1000kg of the sea hare *Dolabella auricularia*. In a similarly large collection, 50 kg (~20,000 individuals) of the small sea hare *Stylocheilus longicauda* were extracted to obtain 12g of Aplysiatoxin (Kato and Scheuer 1975). It is not clear how many sites were used for these collections or the period of time over which the collections were made. However, Kato and Scheuer (1975) indicate that the sea hares were extracted in 500g or 1kg batches, which would require about 200-500 individuals. Consequently, each collection could have removed a significant proportion of the local population.

Reports of the large-scale collection of marine molluscs are uncommon in the literature. However, rare and endemic species will be susceptible to detrimental impacts from much smaller collections. The sea hares mentioned above are relatively common with cosmopolitan distributions. Of greater concern is a study published on the egg masses of an unidentified nudibranch (Matsunaga *et al.* 1986). This study reports the collection of only 120g (12 pieces) of egg mass, which does not seem to be an excessive collection. However, if these 12 'pieces' represent 12 egg masses, it is possible that on a local scale, the entire next generation of the species was collected. Since the nudibranch was not identified it is impossible to assess the impact of this collection. Furthermore, without the correct taxonomic identification it would not be possible to make subsequent collections to study the bioactive compounds. This highlights the need to lodge voucher specimens of all material collected for natural products research.

Problems with the literature

In general, it is very difficult to assess the impacts of marine bioprospecting from the literature. This is because the majority of papers published on marine natural products do not report the quantity of organism that was collected. From a sample of 74 papers on marine molluscs, over half did not report the amount of sample collected (Figure 1a). This was also found to be true of a range of papers published on the natural history and ecology of marine molluscs (Figure 1a), suggesting this may be a general problem with the scientific literature. Concern has also been raised over the fact that bioprospectors rarely provide any indication of the abundance of the organisms they collect (Anderson 1995). Species abundance was reported in only 11 of 74 papers involving the isolation of natural products from marine molluscs (Figure 1b). Papers published in a wide range of Chemistry and Biology journals did not provide information on species abundance (Figure 1b; refer to Benkendorff 1999a, Appendix 1 for a full list of references).

Relevant biological information needs to be regularly reported in the natural products literature to determine if chemical prospecting is ecologically sustainable. The examples illustrate that the minimum information required includes the correct species identification ,the amount of sample collected and the local abundance of all species targeted for natural products research. This type of information is essential for assessing the impacts of bioprospecting and should be a requirement of the editors and referees responsible for reviewing papers for publication.

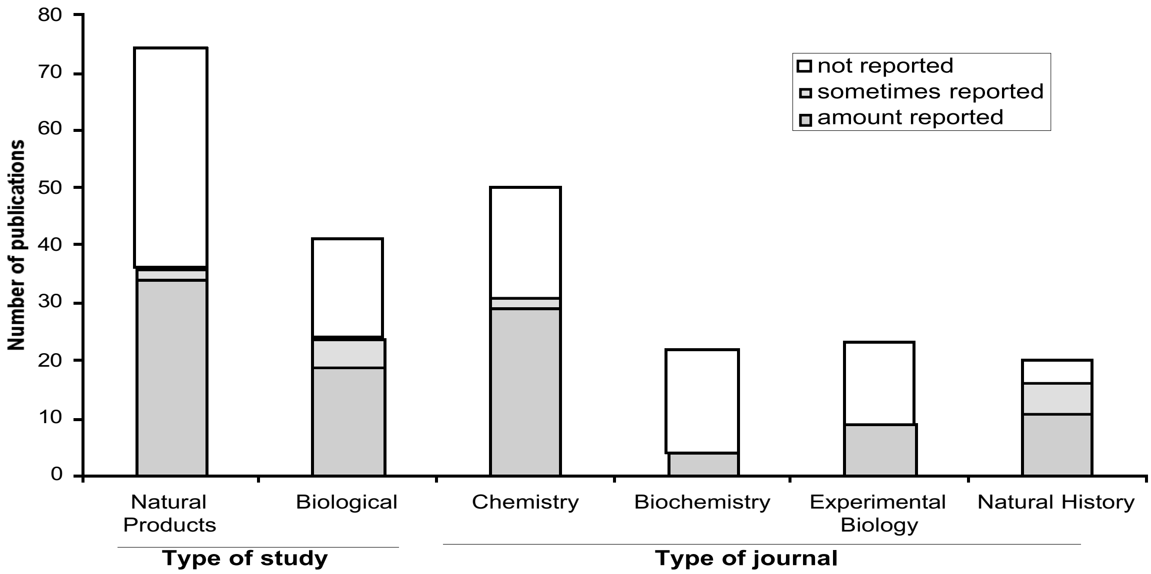

Figure 1: The number of studies reporting; a) the amount of specimens collected; and b)(see over page) the abundance of the species collected from a sample of 74 publications on molluscan natural products and 34 biological publications on molluscs.The studies have also been separated according to the type of journal in which the research was published. Papers that report the amount collected and abundance of some but not all species used in the study are listed as sometimes reported.The list of references are provided by Benkendorff (1999a).

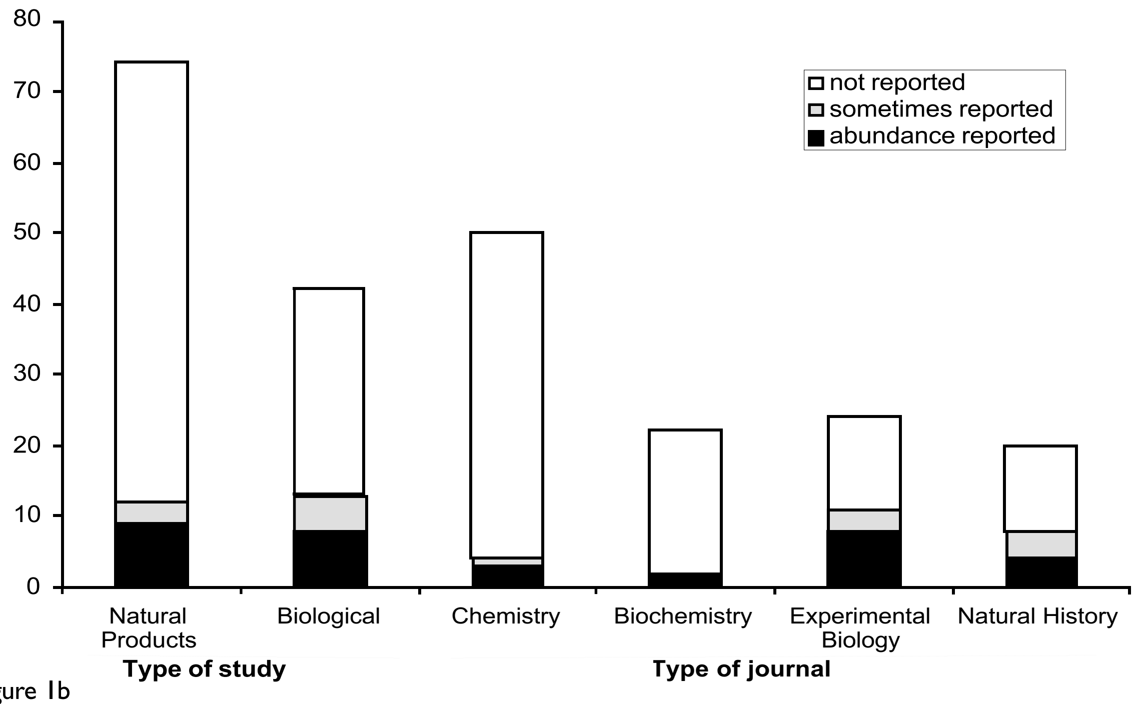

Figure 1b

Potential environmental impacts

Natural products chemists, and indeed all scientific researchers, need to recognise that all research on the natural environment is likely to have some impact. In a resolution adopted by the American Society of Pharmacognosy, the guidelines state that in the pursuit of a biologically active agent, members "will identify activities that might have an adverse impact on the conservation and sustainable use of biological diversity and adopt appropriate measures to change those activities so as to minimize any adverse effects" (Cragg *et al.* 1997b). Environmental impacts could result from inappropriate collecting methods or from features of the collecting location that make it particularly vulnerable to damage (Voumard, 2000). The population size and nature of the species will also influence whether the proposed collection quantities can be sustained. The precautionary principle should be applied for all scientific research on species, populations and ecological communities.

Some biologically relevant recommendations have been made by groups of natural products chemists wishing to ensure that bioprospecting becomes an environmentally sustainable practice. The International Union of Pure and Applied Chemistry recommends that adequate provision be made for the preservation of rare or threatened species "even to the extent of forbidding collections in some circumstances" (Andrews *et al.* 1996a). Similar recommendations were made at a Workshop in Kuala Lumpur (1996). These recommendations are appropriate, however, they overlook the fact that the rarity of many marine organisms is simply not known (e.g. Chapman 1999). A further recommendation is that biological specimens should never be over-collected (Workshop in Kuala Lumpur 1996; *The National Strategy for the Conservation of Australia's Biological Diversity* 1997). Unfortunately, neither document defines "over-collection".

Over-Collection

There are two ways in which over-collection could take place during chemical prospecting. Firstly, the collection of specimens could significantly reduce the local population size leading to a decrease in genetic diversity, genetic drift and possibly local extinction. Alternatively, over-collection could result from the collection of a greater number of specimens than is actually required for the proposed study. This type of over collection may not have serious environmental impacts but it is wasteful and given our lack of knowledge about biological interactions in the marine environment, it cannot be considered compatible with the objectives of conservation. A Code of Ethics published by the Royal Australian Chemical Institute recommends that bioprospectors should take no more specimen than is strictly required and a only small proportion of any one population should be collected (Benkendorff 1999c). The Manila Declaration (1992) takes this further by suggesting that " for live plant specimens, collect cuttings or seeds rather than uprooting whole plants; for marine specimens, wherever possible, collect subsections rather than whole organisms".

Many marine organisms have specialised habitat requirements and small populations making them highly susceptible to over-collection. In order to determine the amount of a particular species that can be sustainably collected one must have a basic understanding of the natural history, distribution and local abundance of that species. Knowledge of the ability of larval stages to disperse (Garson 1996) and the demography of species can also be important in determining the potential for recruitment after collection. This type of information may not be available for many marine organisms, consequently, research on the natural history and ecology of organisms must be given priority. In general, it would be appropriate for natural-product chemists to work in collaboration with biologists, to target species most likely withstand collection.

Recent developments in bioprospecting

The biorational approach

It has been estimated that 98 per cent of marine samples collected by bioprospectors are discarded before there has been any detailed chemical or pharmacological analysis (Anderson 1995; Garson 1996). This indicates that the collections made by bioprospectors should be justified by a suitable hypothesis. The International Society of Chemical Ecology suggests the need for increased "biorational" studies aimed at discovering new biologically active chemicals (Eisner and Meinwald 1989). The biorational approach to the discovery of new natural products has been described in detail by Beattie (1992, 1993, 1994, 1995) and involves the use of biological data to target those species most likely to yield an appropriate natural product. I used this approach successfully to identify a novel source of antibiotics in molluscan egg masses (Benkendorff 1999a; Benkendorff *et al.* 2000a,b). By focussing the research on specific target organisms, the biorational approach effectively reduces the number of species that need to be collected and should also minimize the inadvertent collection of rare and endangered species.

Preliminary screening

The methods used to screen for biological activity will influence the amount of sample organism required for collection. In recent years the quality and efficiency of bioassays has greatly improved. There has been miniaturisation and automation of assays (Liles 1996), as well as the development of a variety of specific enzyme inhibition and receptor antagonist bioassays (Rinehart 1988, Carté 1996). Less than 100 g per species is generally sufficient material for preliminary pharmaceutical evaluation (Voumard, 2000). Provided that the target species have large sustainable populations in the collection area, preliminary collections should have minimal environmental impact.

Isolation and structure elucidation

The identification of active components will typically require a great deal more sample than the initial screening. It is in the recollection of bioactive organisms that there is a real risk of adverse environmental impacts. Nevertheless, the modern instruments available for elucidating the structure of natural products have very small sample requirements. For example, only nanogram quantities of material are required to obtain an accurate molecular mass and fragmentation pattern of a compound under electron impact using Mass Spectroscopy (MS). In combination with the non-destructive techniques of high field Nuclear Magnetic Resonance spectroscopy it is possible to identify unknown compounds from only a few milligrams of sample.

Using modern spectroscopic techniques, I was able to identify three antimicrobial compounds from the egg mass of the common dog whelk *Dicathais orbita* (Benkendorff *et al.* 2000a). In total, 300 g of egg mass were collected for the isolation of these compounds, which is only a tiny proportion of the local population. A study by Cimino *et al.* (1988) further illustrates the small sample requirements of the modern analytical techniques used by natural products chemists. These researchers collected only a single specimen of the sea slug *Umbraculum mediterraneum*, which they reported as rare. The skin of this specimen was extracted and two diacylglycerols were identified using spectroscopic techniques. Complete structural elucidation and an assessment of the toxicity to fish was carried out on a total of only 8 mg of one compound and 10 mg of the other. These studies illustrate that natural products research can be sensibly undertaken in the marine environment using small sample collections.

Nevertheless, the actual amount of sample required for natural products research will vary depending on the amount of the active compound present in the organism and the complexity of its chemical structure. Some organisms contain only tiny amounts of very potent chemicals, so huge collections are required. For example, Garson (1996) reports that in one study, 2400 kg of sponge were collected to isolate only 1 mg of an anticancer chemical. In these cases, further collections should be justified by the demonstrated ability of the species to recover after such large collections. It has been suggested that an environmental impact assessment should performed for each target species prior to recollection (Garson 1996; Workshop in Kuala Lumpur 1996; Voumard, 2000).

Supply for the pharmaceutical industry

A major problem preventing pharmaceutical companies from investing in marine bioprospecting is the issue of supply. In some cases the active compounds may be simple enough to permit chemical synthesis, such as the antibiotic tyriverdin (2,2'-Bis (methylthio)-6,6'-dibromoindigotin) derived from the egg mass of *Dicathais orbita* (Benkendorff *et al.* 2000a). Nevertheless, it is necessary to distinguish between "academic synthesis" and "industrial synthesis", where the aim is to produce large quantities of the material at a low cost. Synthetic processes for the production of marine natural products usually require multiple steps and the cost of reagents can be prohibitively expensive (Pomponi 1999). Most marine natural products are highly complex making it impossible to synthesize them in industrial quantities.

Other options for the industrial production of marine natural products depend on biosynthesis. Prior to the large-scale wild harvest of an organism, an environmental impact study must be conducted and a long-term monitoring program implemented. Wild harvest has been used to obtain an anticancer compound from the common fouling organism *Bugula neritina* (Pomponi 1999), but in most cases marine organisms will not be sufficiently abundant to sustain large scale harvesting. One alternative is to farm the bioactive marine organisms in aquaculture. A group of researchers working on anticancer chemicals from a geographically restricted sponge have made remarkable progress in farming this sponge in New Zealand waters (Munro *et al.*, 1999). The Australian Institute of Marine Sciences has also indicated it's intention to develop methods for supplying bioactive compounds from marine organisms through aquaculture (Starvo 2000). Not all marine organisms will be suitable candidates for aquaculture. However, recent research indicates that many bioactive marine natural products are actually being produced by microorganisms present in the tissues of marine invertebrates (Garson 1996). Consequently, it may be possible to culture these microbes. Alternatively, genetic engineering could be used to produce some types of compounds in common laboratory microorganisms. Overall, there is a range of options for the large-scale production of interesting metabolites that avoid destructive harvesting from the natural environment.

Conclusion

Bioprospecting has immense potential to be used as a tool for conservation, but only if it is demonstrated to be ecologically sustainable. There has been considerable concern over the adverse environmental impacts of marine bioprospecting and there are indications that some marine organisms have been over-collected. There are also serious problems associated with the lack of biological information published in the literature. However, with recent advances in screening technologies and modern analytical instruments it is possible to identify natural products from ever-smaller quantities of material. The development of alternatives for the large-scale collection of marine natural products should further ensure the sustainability of the marine bioprospecting industry. Most encouragingly, several prominent groups of natural-products chemists have produced resolutions, guidelines and codes of ethics that should help regulate the bioprospecting industry and draw the attention of chemists to the importance of biological information (*The Manila Declaration* 1992; *The Melaka Accord* 1994; Andrews *et al.* 1996a,b; Workshop in Kuala Lumpur 1996; Cragg *et al.* 1997b; Benkendorff, 1999c). However, there is some scepticism over the efficacy of self-administered rules. Consequently, the bioprospecting industry should be regulated by appropriate government agencies. Contractual agreements between the land owners and bioprospectors provide opportunities to ensure the use of best practice procedures and to trigger a process of environmental impact assessment.

If undertaken in an environmentally sustainable manner, bioprospecting could be used to help attain the objectives of conservation through; 1) financial benefits; 2) facilitating biodiversity research; and 3) increasing the community's awareness and appreciation for biodiversity. In return for access to biological diversity pharmaceutical companies can provide financial benefits in the form of fees and royalties. However, economic incentive alone is unlikely to provide a significant contribution to the sustainable management of biodiversity. Contractual agreements could stipulate that some of the financial returns from bioprospecting are to be used to fund environmental projects. Alternatively, financial support for biodiversity research could be encouraged. All bioprospecting agreements should incorporate a mandatory requirement to lodge representative samples and biogeographical information in accredited institutions. This will ensure that bioprospecting contributes to our knowledge of biodiversity and provides a resource for further scientific research.

Bioprospectors can also raise awareness about biodiversity and conservation issues by communicating with members of the community directly or through the media. The need for conservation is more likely to be appreciated if people are aware of the wide variety of resources that nature provides. The opportunity for obtaining a novel resource with low environmental impact may strengthen the case for maintaining natural ecosystems in the face of competing uses (Farrier and Tucker 1998). It has been suggested that moral and ethical reasons for conservation should be promoted rather than the potential utilitarian value of species, because only a small proportion of species will turn out to be useful (Ehrenfeld 1988; Lawton 1991). However, the commodity value of biodiversity is likely to be much greater than is generally realised (Beattie 1992; 1993; 1994; 1995; Benkendorff 1999d). Furthermore, ethical arguments are unlikely to gain acceptance in a world that continues to be dominated by the market place (Randall 1991). Another concern is that the economic criteria of value are fluid and opportunistic in their practical applications (Ehrenfeld 1988). However, the very fact that human needs and values change means that it is impossible to rule out any species as not worth saving. All species should be assigned an 'option' value to allow for the "possibility that a future discovery will make useful a species that we currently think is useless" (Norton 1988).

Acknowledgments

I would like to thank Dr. A. Davis and Dr Cary Rodgers from the Department of Biological Sciences, as well as Professor J. Bremner from the Department of Chemistry at the University of Wollongong for helpful suggestions. Financial support from the University of Wollongong is also appreciated.

References

Aalbersberg, B. 1997. Biodiversity prospecting in the seas around Verata Tikina. In *Biodiversity Conservation Network, Annual Report 1997*. Biodiversity Conservation Network, Washington, DC.

Anderson, I. 1995. Oceans plundered in the name of medicine. *New Scientist*. **148** (2005):5.

Andrews, P.R., Borris, R., Dagne, E. Gupta, M.P., Mitscher, L.A., Monge, A., De Souza, N.J. and

Topliss, J.G.. 1996a. Preservation and utilization of natural biodiversity in context of search for economically valuable medicinal biota. Recommendations. *Pure and Applied Chemistry* **68**: 2325-2332.

Andrews, P.R., Borris, R., Dagne, E. Gupta, M.P., Mitscher, L.A., Monge, A. and De Souza, N.J. 1996b. General features of contracts for natural product collaborators. Technical Report. *Pure and Applied Chemistry* **68**: 2333-2337

Asebey, E.J. and Kempenaar, J. D. 1995. Biodiversity prospecting: Fulfilling the mandate of the biodiversity convention. *Vanderbilt Journal of Transnational Law* **28**: 703-754

The Australian Science, Technology and Engineering Council. 1998. *Environmental Research Ethics: National Principles and Guidelines for the Ethical Conduct of Research in Protected and Environmentally Sensitive Areas*. Pp 48-49. Commonwealth of Australia. Ausinfo. Canberra, ACT.

Barrett, C.B. and Lybbert, T.J. 2000. Is bioprospecting a viable strategy for conserving tropical ecosystems? *Ecological Economics* **34**: 293-300.

Beattie, A.J. 1992. Discovering new biological resources - chance or reason? *Bioscience* **42**: 290-292

Beattie, A.J. 1993. Conservation, evolutionary biology and the discovery of future biological resources. Pages. 305-312 in *Conservation Biology in Australia and Oceania* ed. by C. Moritz and J. Kikkawa, Surrey Beatty and Sons, Sydney.

Beattie, A.J. 1994. Invertebrates as economic resources. *Memoirs of the Queensland Museum* **36**: 7-11.

Beattie, A.J. 1995. Natural history at the cutting edge. *Ecological Economics* **13**:93-97.

Benkendorff, K. 1999a. *Bioactive Molluscan Resources and Their Conservation: Biological and Chemical Studies on the Egg Masses of Marine Molluscs.* PhD Thesis, University of Wollongong.

Benkendorff, K. 1999b. *The Shellharbour and Bass Point Marine Environment*. Report for Shellharbour City Council, NSW, Australia. 46 pp.

Benkendorff, K. 1999c. Sustainable bioprospecting. *Chemistry in Australia.* **66** (9):14-16.

Benkendorff, K. 1999d. Molluscan Resources: The past present and future value of molluscs. Pp. 316-321 in *The Other 99%. The Conservation and Biodiversity of Invertebrates.* Ed. by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales. Mosman, NSW.

Benkendorff, K., J.B. Bremner, and A.R. Davis. 2000a. A putative role for the precursors of Tyrian Purple in the egg masses of the Australian Muricid, *Dicathais orbita*. *Journal of Chemical Ecology* **26**:1037-1050.

Benkendorff, K., A.R. Davis, and J.B. Bremner. 2000b. Rapid screening for antimicrobial agents in the egg masses of marine molluscs. *Journal of Medical and Applied Malacology* **10**: 211-223.

Cartè, B. 1996. Biomedical potential of marine natural products. *Bioscience* **46**(4): 271-285.

Cimino, G., Crispino, A., Spinella, A. and Sodano, G. 1988. Two ichthyotoxic diacylglycerols from the opisthobranch mollusc *Umbraculum mediterraneum*. *Tetrahedron Letters* **29**:3613-3616

Chapman, M.G. 1999. Are there adequate data to assess how well theories of rarity apply to marine invertebrates? *Biodiversity and Conservation* **8**: 1295-1318.

Commonwealth Government. 1994. *Access to Australia's Biological Diversity- A Discussion Paper*. Australian Government Publishing Service, Canberra.

Commonwealth-State Working Group on Access to Australia's Biological Resources. 1997. *Managing Access to Australia's Biological Resources: Developing a Nationally Consistent Approach- A Discussion Paper.* Commonwealth Government, ACT.

***The Convention on Biological Diversity.* 1992.** Rio de Janero.

Cragg, G.M., Newman, D.J. and Snader, K.M. 1997a. Natural products in drug discovery. *Journal of Natural Products* **60**:52-60.

Cragg, G.M., Baker, J.T., Borris, R.P., Cart è, B., Cordell, G.A., Soejarto, D.D., Gupta, M.P., Iwu, M.M., Madulid, D.A. and Tyler, V.E. 1997b. Interactions with source countries. Guidelines for members of the American Society of Pharmacognosy. *Journal of Natural Products* **60**:654-655.

Ehrenfeld, D. 1988. Why put a value on biodiversity? Pp 212-216 in *Biodiversity*. E.O. Wilson (Ed.), National Academy Press, Washington D.C.

Eisner, T. 1990. Prospecting for nature's chemical riches. *Issues in Science and Technology* **6**(2):31-34.

Eisner, T. and Meinwald. 1989. *The Göteborg Resolution*. International Society for Chemical Ecology. Reprinted in *Chemoecology* **1** (1990):38.

Farrier, D. and Tucker, L. 1998. Access to marine biological resources and the conservation of marine biodiversity. '*Legal Issues in Management of the Marine Environment*' workshop, Qingdao, China, April 27-28, 1998.

Farrier, D. and Tucker, L. 2001. Access to marine bioresources: Hitching the conservation cart to the bioprospecting horse. *The International Journal of Marine and Coastal Law.* In press.

Garson, M. 1996. Is marine bioprospecting sustainable? *SEARCH*, **27**(4): 114-116.

Garson, M. 1997. Marine resources: Cure-all or lose all? *Nature Australia.* **25**(8):80.

Kato, Y. and Scheuer, P.J. 1975. The aplysiatoxins. *Pure and Applied Chemistry* **41**:1-14.

Lawton, J. 1991. Are species useful? *Oikos* **62**: 3-4.

Liles, G. 1996. Gambling on marine biotechnology. *Bioscience* **46**(4):250-253.

***The Manila Declaration.* 1992.** Seventh Asian Symposium on Medicinal Plants, Spices and Other Natural Products. Manila, Philippines, February 2-7, 1992. Reprinted in *Pure and Applied Chemistry* **68**: 2329-2331.

Matsunaga, S., Fusetani, N. and Hashimoto, K. 1986. Kabiramide C, a novel antifungal macrolide from nudibranch eggmasses. *Journal of the American Chemical Society* **108**: 847-849.

***The Melaka Accord.* 1994.** Eighth Asian Symposium on Medicinal Plants, Spices and Other Natural Products. Melaka, Malaysia, 12-16 June, 1994. Reprinted in *Pure and Applied Chemistry* **68**: 2331-2332.

Munro, M.H.G., Blunt, J.W., Dumdei, E.J., Hickford, S.J.H., Lill, R.E., Li, S., Battershill, C.N. and Duckworth, A.R. 1999. The discovery and development of marine compounds with pharmaceutical potential. *Journal of Biotechnology* **70**: 15-25.

***National Strategy of the Conservation of Australia's Biological Diversity,* 1997.** Commonwealth Government, Canberra Australia.

Norton, B. 1988. Commodity, amenity and morality-The limits of quantification in valuing biodiversity. Pp 200-205 in *Biodiversity*. Ed. E.O. Wilson, National Academy Press, Washington D.C.

Pettit, G.R., Kamano, Y., Herald, C.L., Tuinman, A.A., Boettner, F.E., Kizu, H., Schmidt, J.M., Baczynskyj, L., Tomer, K.B. and Bontems, R. 1987. The isolation and structure of a remarkable marine animal antineoplastic constituent: Dolastatin 10. *Journal of the American Chemical Society* **109**: 6883-6885.

Pomponi, S.A. 1999. The bioprocess – technological potential of the sea. *Journal of Biotechnology* **70**: 5-13.

Ponder, W.F. 1999. Using museum collection data to assist in biodiversity assessment. Pp 253-256 in *The Other 99%. The Conservation and Biodiversity of Invertebrates.* Ed. by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales. Mosman, NSW.

Randall, A. 1991. The value of biodiversity. *AMBIO* **20**: 64-67.

Rinehart, K.L. 1988. Screening to detect biological activity. Pp 13-22 in *Biomedical Importance of Marine Organisms*. Ed. by D.G. Fautin. California Academy of Sciences.

Roberts, L. 1992. Chemical prospecting: Hope for vanishing ecosystems? *Science* **256**: 1142-1143.

Sittenfeld, A. and Villers, R. 1993. Exploring and preserving biodiversity in the tropics: the Costa Rican case. *Current Opinion in Biotechnology* **280**: 283.

Smith, R.S. 1999. 'Bugging' the media: TV broadcasting and the invertebrate agenda. Pp 413-417 in *The Other 99%. The Conservation and Biodiversity of Invertebrates.* Ed. by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales. Mosman, NSW.

Starvo, A. 2000. Drug search turns to sea. *The Weekend Australian* **February 26-27, 2000**: 20.

Tangley, L. 1996. Ground rules emerge for marine bioprospectors. *Bioscience* **46**:245-249.

Voumard, J. (Commonwealth Public Inquiry Chair) 2000. *Access to Biological Resources in Commonwealth Areas.* Environment Australia, Canberra, ACT.

Wilson, B. 1993. *Australian Marine Shells.* Odyssey Publishing. Kallaroo, Western Australia.

Wilson, E.O. 1994. *The Diversity of Life.* Penguin Books Australia Ltd, Victoria.

Workshop in Kuala Lumpur 1996. *Guidelines to facilitate access to biological resources and the equitable sharing of benefits in the south east Asian Region.* UNESCO subregional office Jakarta, the Ministry of Science, Technology and the Environment, Malaysia and the International Foundation for Science. April 6-9, 1996.