When should restocking and stock enhancement be used to manage sea cucumber fisheries?

Johann Bell[33] and Warwick Nash[34]

Abstract

Access to technology for producing and releasing juveniles is not a sufficient rationale to proceed with restocking (restoring stocks to the point where they can sustain regular harvests) or stock enhancement (increasing yields by overcoming recruitment limitation) of sea cucumber populations. Rather, careful decisions need to be made about whether these interventions are likely to be cost-effective ways of improving productivity. Although restocking is designed to restore severely depleted stocks, it will be essential to determine whether the release of cultured juveniles will significantly reduce the time needed for replenishment compared to other forms of management, e.g., a total moratorium on fishing or artificially aggregating and protecting some of the wild adults to promote spawning success. This will require an evaluation of population recovery rates under various interventions and restocking scenarios using both theoretical (life table analysis and population modelling) and empirical approaches. The information needed for such comparisons includes: remnant stock size, population age/size composition, generation time, longevity, fecundity, annual variation in the recruitment rate, natural mortality at different life stages and behaviour of the species that may affect spawning success or survival at low population density. Investments in hatchery production for restocking should only proceed when the modelling described above demonstrates that releases of cultured animals will "fast-track" replenishment considerably.

Stock enhancement can be considered once sea cucumber fisheries have been rebuilt to the desired level of spawning biomass, although it can only be expected to be of benefit where the supply of juveniles regularly falls well short of the desired levels of recruitment. To assess whether stock enhancement is likely to be effective, managers need sound information on: the carrying capacity of the habitat for sea cucumbers, optimal stocking density, the abundance and age structure of the stock, the natural supply of juveniles each year, the cost of cultured "seed" and post-release survival rates. Even where the supply of juveniles falls short of the desired level, stock enhancement will not be appropriate if the cost of producing the juveniles exceeds the value of the additional harvests expected to result from the releases.

Another important point is that stock delineation is central to the success of restocking and stock enhancement programs: the assessments described above need to be made at the level of self-replenishing populations within the stock.

Keywords: Restocking, stock enhancement, management, population modelling

何时增殖放流有利于海参渔业？

J. 贝尔[1]、W. 纳什[2]

[1]马来西亚，世界渔业中心；[2]新卡里托尼亚，世界渔业中心

摘要

试图通过生产和放流海参种苗来维持海参渔场的可持续生产和增产，从原理上讲，尚有待商榷。更清楚地讲，在做出这一决定前，要了解为了改善生产而采取这一措施在成本上是否合算。虽然增殖放流是为了增加资源严重衰退渔场的资源补充量，但是若与其它方法，如延迟捕捞期、人为地将亲参聚集到一起，或者保护野生成年个体来提高生殖能力等相比，在资源恢复的时间上是否会明显地缩短是值得研究的。这就需要对各种增殖方式、方法，无论是理论上的（如死亡率分析和种群模式）还是经验上的做法，都需要从资源恢复率的角度予以评价。若要做好对比分析，需要如下资料：剩余资源大小、种群年龄/大小组成、世代间隔时间、寿命、生殖力、资源补充量的年变化、不同生活周期的天然死亡率、以及在低种群密度时影响产卵率和受精率的种质行为等。为资源增殖而投资于海参苗种生产只有当上述模式证明，人工培育的海参用于放流会相当快地使得资源得到补充才可考虑。

资源增殖是期望重建海参渔业，使得产卵群体生物量达到所希望的水平，因为这类渔场自然幼苗补充量达不到所要求的水平。要评价资源增殖是否有效，管理者需要掌握全面的信息：海参栖息地的容纳量、最优资源密度、资源量的丰度和年龄结构、每年的自然幼苗量、人工育苗费用和放流前的存活率等。即使幼苗补充量低于所需水平，但繁殖幼苗的费用超过了放流前所期望的收获物的附加值，资源增殖也是不合适的。

另一要点是，考察放流和资源增殖项目成功与否，要看种群内部自身补充量是否达到应有的水平。

关键词：放流、资源增殖、管理、种群模式

Introduction

Populations of sea cucumbers are being overfished worldwide (Battaglene and Bell, 2004; Conand, 2004; Lawrence et al., 2004; Altamirano et al., 2004; Uthicke, 2004). This is now causing major concerns for fishers and managers because these easily accessible, inshore resources are no longer able to provide their potential economic benefits. Not surprisingly, managers are investigating whether the release of hatchery-reared juveniles may be a useful tool to restore the production of sea cucumbers. Indeed, considerable efforts are now being made to develop methods for mass-production of juveniles in hatcheries (Battaglene, 1999; Battaglene et al., 1999; Hamel et al., 2001; Chen, 2004; James, 2004; Mercier et al., 2004; Pitt and Duy, 2004), and for releasing juveniles in the wild at good rates of survival (Purcell et al., 2002; Battaglene and Bell, 2004; Dance et al., 2003; Purcell, 2004). However, we believe that not enough thought has yet been given to whether the relatively expensive option of producing juveniles in hatcheries will actually add value to other measures to promote replenishment available to managers of sea cucumber fisheries. Rather, assumptions seem to have been made that any additions of cultured juveniles will be of benefit and that it is just a matter of learning how to produce them at low cost, and release them at sizes and in ways that enable them to survive in high proportions.

It is now apparent that many other questions need to be answered before decisions are made to invest in a hatchery program for sea cucumbers. These questions include:

1. Is the fishery comprised of one large homogeneous population, or is it divided into several, largely self-replenishing, populations?

2. What is the abundance and size structure of each population comprising the fishery, and how does the current status of the population compare to the original unexploited level?

3. What is the purpose of releasing cultured juveniles? Is it to restore spawning biomass to a more productive level? (a process referred to as "restocking" by Battaglene and Bell, in press; Bell, in press), or is it to increase yields from a fishery where spawning biomass is close to the desired level, but production is lower than the potential carrying capacity of the habitat due to recruitment limitation? (a process described as "stock enhancement" by Doherty, 1999; Battaglene and Bell, in press; Bell, in press).

4. Can the aims of management, to rebuild the spawning biomass of severely overfished populations, or to increase the productivity of "healthy" populations, be met cost-effectively with other forms of management?

In this paper, we discuss these issues in more detail to provide guidance on the main factors that need to be considered in restoring depleted fisheries for sea cucumbers, or enhancing the production of those fisheries that are still in relatively good condition.[35] Our main conclusions are that: 1) population modelling is needed to assess whether hatchery release programs will add value to other forms of management designed to replenished over-exploited fisheries; and 2) the immediate purpose of research on the hatchery production of sea cucumbers, and effective ways for releasing them in the wild, should be to provide the information needed for the models designed to evaluate the merit of different approaches to restoring the productivity of sea cucumber fisheries.

Why is stock delineation so important?

To date, there has been interest in identifying the genetic population structure of various species of sea cucumber (Uthicke and Benzie, 2001; Uthicke and Purcell, in press) to ensure that hatchery-reared juveniles are produced and released in ways that do not affect the natural genetic diversity of the species. These studies have shown that for at least one species, *Holothuria scabra,* there can be marked differences between populations at relatively small spatial scales. This is strong evidence that national fisheries for this valuable species are likely to be targeted at more than one largely self-recruiting population. The implication is that each of these populations will need to be managed separately.

This begs questions about the population structure and exploitation patterns of other species of sea cucumbers. How many self-recruiting populations occur within the distribution of the species? What is the spatial scale of these populations? Which groups of fishers share in the harvests from each population? Without this information, national managers cannot begin to develop optimum strategies for restoring or enhancing the production of each species of sea cucumber.

A word of caution here: population genetic studies may not be sensitive enough to detect the number and scale of all largely self-recruiting populations within a fishery because relatively low levels of reproduction between adjacent populations may be sufficient to maintain gene flow even when the populations are largely self-recruiting. This means that the results of the most sensitive genetic analyses should be taken as a measure of the minimum number of management units. Other analyses, e.g. of symbionts and parasites, may be needed to help identify the distributions of all largely self-recruiting populations of the species. Hamel *et al.* (1999) report an interesting example of a symbiotic relationship between a pea crab and *Holothuria scabra* at a small spatial scale in Solomon Islands.

The role of stock assessments

Once the number of largely self-recruiting populations within a fishery has been identified, assessments of the abundance of size/age classes need to be made for each population. For many species of sea cucumbers, this can be done relatively easily using underwater visual transects (Lincoln-Smith *et al.,* 2000). However, for species that occur in turbid water, standardized trawl or dredge surveys will be required. Estimates of population size using either of these area-based sampling methods are not straightforward because the distribution of sea cucumbers is often highly patchy, which can lead to substantial errors in total abundance when the fished population covers a large area unless the survey is stratified and replicated appropriately. In cases where resources are inadequate for such surveys, it may be possible to make estimates of population depletion and, importantly, the remnant population from temporal changes in catch rates, size composition and localities fished. Data on the status of each population can then be used to decide whether it is at such a low ebb that stringent measures need to be taken to restore the spawning biomass to more productive levels, or whether the primary need is to find efficient ways to make the relatively robust population more productive.

Modelling the potential benefit of releasing hatchery-reared juveniles

Restocking

For populations where stock assessments reveal that spawning biomass is at chronically low levels, the temptation will be to assume that the release of hatchery-reared juveniles will help restore the number of spawners. However, for such restocking to be effective, the remnant wild sea cucumbers and the released animals would need to be protected until they and their progeny replenish the population to the desired spawning biomass. If this is the case, managers need to ask whether a moratorium on fishing for the remnant wild population alone would be sufficient to achieve replenishment. This important decision can be made on the basis of some relatively simple modelling.

By estimating how long it would take for the number of spawners to be restored to the desired level using a moratorium alone, managers should then be able to determine whether the addition of more juveniles through a restocking program will add significant value. The basic information needed to construct a model for predicting the exponential rate of replenishment under a moratorium includes: remnant stock size and density, population age/size composition, generation time, longevity, fecundity, annual variation in the recruitment rate, natural mortality at different life stages and behaviour of the species that may affect spawning success or survival at low population density.

Modelling whether the release of hatchery-reared juveniles would be a cost-effective way of reducing the time needed to re-build the desired number of spawning sea cucumbers, compared to replenishment under a moratorium alone, would depend on the following additional information: survival to adulthood of cultured juveniles released in the wild, and the cost of producing the juveniles. Assumptions are made here that the cultured juveniles do not have deficits that would prevent them from spawning; that they are released at densities that do not inhibit their growth or survival; and that they are produced and released in way that does not alter the gene pool of the population into which they are placed (Munro and Bell, 1997; Battaglene and Bell, 1999, in press; Uthicke and Purcell, in press).

Modelling the benefits of adding cultured juveniles should be made at several different magnitudes of release to identify what numbers of animals are needed to substantially reduce the time needed for replenishment. The gain in terms of reduced number of years before the fishery can be re-opened at different levels of restocking can then be weighed against the cost of the investment in a hatchery to produce the required number of juveniles. Clearly, a restocking program should only be used if the value of harvests in the years gained from reopening the fishery earlier (due to the hatchery releases) exceed the costs of producing the juveniles.

Variations on the modelling proposed above might include, for example, the use of marine protected areas to protect a large portion of the remnant wild stock in situations where it is not possible to put a moratorium on sea cucumbers because they form part of the catch of a multi-species trawl fishery, and where survival of animals returned to the water is not good due to damage in the nets. Where it is possible to apply a moratorium, recovery could also be accelerated by aggregation of the remnant stock at several places within the distribution of the population and transplanting aggregations large enough to spawn effectively to areas within the distribution of the self-replenishing population where successful settlement of juveniles has not occurred (Battaglene and Bell, in press). These measures should increase the probability of reproductive success and promote the dispersal of larvae to unoccupied settlement habitat.

One problem with applying this approach to sea cucumbers is that with the exception of afew species, *e.g. Apostichopus japonicus* and *Holothuria scabra,* the basic life history information needed for the modelling is often not available. In such cases, however, it should be possible to place species into broader 'life table' categories (see Hempell and Crowder, 1998) to approximate the response to total protection from fishing and to addition of cultured juveniles, where urgent restoration of a population is needed. Where the minimum necessary information to place species into life table categories is not currently available, managers should commission the research urgently.

Stock Enhancement

Assessing the potential benefit of releasing cultured juvenile sea cucumbers in a stock enhancement program requires a different approach. Such interventions should only be considered where there is strong evidence that the habitat does not regularly receive as many juveniles, through the natural supply of post-larvae, as it is capable of supporting and as are desired by managers (Munro and Bell, 1997; Doherty, 1999; Battaglene and Bell, in press). If this is the case, managers need to calculate how many more sea cucumbers could be supported if they were available and to identify optimal stocking densities. The latter point is critical - for species that take several years to reach the recommended minimum legal size, it would be a mistake to release as many individuals as the habitat could support in one year, i.e. they should not seek to fill the "carrying capacity" of the habitat. To do so would limit the number of individuals that could recruit successfully the following year without retarded growth and survival and result in an age structure dominated by one year class. Ultimately, this will result in a large harvest one year, followed by years of much lower production. Such variation is not in the best interests of fishers or markets.

A better approach would be to release fewer animals each year so that the optimal biomass is achieved by an accumulation of year classes. This process can be optimised by using average natural mortality and growth rates to allocate carrying capacity to size/age classes in a way that delivers comparable harvests each year. This (hypothetically ideal) size/age structure can then be compared to that of the wild population, and juveniles can then be added each year to provide the number needed to give the optimum harvest by the time the sea cucumbers grow to the minimum legal size (see Figures 2 and 3 in Bell, in press, for more details). In practice, this requires close monitoring of settlement success to detect sub-optimal levels of recruitment, or recruitment failure, followed by swift production and release of the desired number of juveniles when there is a shortfall in the natural supply. Where this cannot be done practically, which will be the case for some species, stock enhancement will need to be planned in a coarser way. For example, if settlement success cannot be measured until the animals are one year old, then managers have little option but to respond then, although they will always run the risk of releasing juveniles in response to a previous recruitment failure at a subsequent time of adequate natural supply. Alternatively, managers could hedge their bets by releasing low densities of juveniles each year and accept that in some years their efforts will be negated by good natural supply, while in others the releases will not be sufficient to maintain the desired age structure for optimum harvests.

Regardless of the sophistication of the approach used, the variation in the natural supply of juveniles each year, and the projected survival of released juveniles to harvest size, can be used to identify the range of juveniles likely be needed to supplement natural recruitment among years. This range will determine the investments needed to construct hatcheries with the necessary capacity. Ultimately, decisions to invest in stock enhancement programs will need to be based on assessments that the added value of the increased harvests stemming from hatchery releases exceeds the cost of producing the juveniles.

Other important considerations

Much of the research to date on hatchery production of sea cucumbers, and methods for releasing them in the wild, has been done by national research agencies, universities and regional and international organizations. Future decisions about when to apply these interventions, and payment of the cost involved, are likely to be made by different groups for restocking and stock enhancement. There is rapidly growing awareness that stock enhancement programs should no longer be funded by government. Rather, the direct beneficiaries should bear the costs (Lorenzen *et al.,* 2001). However, there must be an incentive for doing so. Consequently, decisions to engage in stock enhancement by the private sector, or fisheries co-operatives, are only likely to occur in places where fishers are granted access or property rights (Bell, in press and references therein). Identifying who should pay the costs of restocking programs is not so straightforward. Rebuilding severely depleted fisheries with the assistance of restocking programs will probably remain the responsibility of governments until the private sector is convinced that the process will succeed. Then, the private sector may be prepared to bear the costs in exchange for property rights.

Conclusions

Although the release of cultured sea cucumbers holds much promise as a tool to assist managers to restore severely depleted populations, or to optimise the production from populations that are still in relatively good condition, there has been little understanding about how research on development of hatchery and release methods best helps managers to assess whether such interventions will be cost-effective. It is now clear that research to reduce the cost of producing environmentally fit, genetically diverse cultured juveniles, and to release them in the wild so that they survive in high proportions, should be used for two different purposes.

The first purpose is to enable managers to model whether hatchery releases are likely to add value to other forms of management, e.g. a moratorium on fishing, where the imperative is to rebuild a severely overfished population.

The second purpose is to improve the efficiency of using hatchery-reared juveniles where these interventions have been deemed to be of benefit on the basis of thorough analyses. Investments in release programs for sea cucumbers in most other circumstances run the strong risk of misappropriating resources that could have been used to increase productivity in other ways.

Acknowledgements

We thank Alessandro Lovatelli (FAO, Fisheries Department) for the invitation to prepare this manuscript. This paper is WorldFish Contribution No. 1701.

References

Altamirano, M., Toral-Granda, V. & Cruz, E. 2004. The application of the adaptive principle to the management and conservation of *Isostichopus fuscus* in the Galápagos Marine Reserve. *In: Advances in sea cucumber aquaculture and management.* A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Battaglene, S.C. 1999. Culture of tropical sea cucumbers for the purposes of stock restoration and enhancement. *Naga, ICLARM Quarterly,* 22(4):4-11.

Battaglene, S.C. & Bell, J.D. 1999. Potential of the tropical Indo-Pacific sea cucumber. *Holothuria scabra,* for stock enhancement. *In: Stock Enhancement and Sea Ranching.* B.R. Howell, E. Moksness and T. Svasand. (Eds.). pp. 478-490. Blackwell Science, Oxford.

Battaglene, S.C., Seymour, E.J. & Ramofafia, C. 1999. Survival and growth of cultured juvenile sea cucumbers *Holothuria scabra. Aquaculture,* 178:293-322.

Battaglene, S.C. & Bell, J.D. In press. The restocking of sea cucumbers in the Pacific Islands. *In: Case Studies in Marine Ranching.* D.M. Bartley and K.M. Leber. (Eds.). FAO Fishery Technical Paper No 429. FAO. Rome.

Bell, J.D. 2004. Management of restocking and stock enhancement programs: the need for different approaches. *Proceedings of the Second International Symposium on Stock Enhancement and Sea Ranching.*

Chen, J. 2004. Present status and prospects of the sea cucumber industry in China. *In: Advances in sea cucumber aquaculture and management.* A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Conand, C. 2004. Present status of world sea cucumber resources and utilization: an international overview. *In: Advances in sea cucumber aquaculture and management.* A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Dance, S.K., Lane, I. & Bell, J.D. 2003. Variation in short-term survival of cultured sandfish *(Holothuria scabra)* released in mangrove-seagrass and coral reef flat habitats in Solomon Islands. *Aquaculture,* 220:495-505.

Doherty, P. 1999. Recruitment limitation is the theoretical basis for stock enhancement in marine populations. *In: Stock Enhancement and Sea Ranching.* B.R. Howell, E. Moksness andT. Svåsand. (Eds.). p.9-21. Blackwell Scientific Publications, Oxford.

Hamel, J. F., Conand, C., Pawson, D. & Mercier, A. 2001. The sea cucumber *Holothuria scabra* (Holothuroidea: Echinodermata): its biology and exploitation as beche-de-mer. *Advances in Marine Biology,* 41:129-223.

Hamel, J.-F., Ng, P.K.L. & Mercier, A. 1999. Life cycle of the pea crab *Pinnotheres halingi* sp. nov., an obligate symbiont of the sea cucumber *Holothuria scabra* Jaeger. *Ophelia,* 50:149-175.

Heppell, S.S. & Crowder, L.B. 1998. Prognostic evaluation of enhancement programs using population models and life history analysis. *Bulletin of Marine Science,* 62:495-507.

James, D.B. 2004. Captive breeding of the sea cucumbers *Holothuria scabra* from India. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Lawrence, A. J., Ahmed, M., Hanafy, M., Gabr, H. & Ibrahim, A. 2004. Status of the sea cucumber fishery in the Red Sea: the Egyptian experience. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Lincoln-Smith, M.P., Bell, J.D., Ramohia, P. & Pitt, K.A. 2000. *Testing the use of marine protected areas to restore and manage tropical multispecies invertebrate fisheries at theArnavon Islands, Solomon Islands.* Great Barrier Reef Marine Park Authority Research Publication 69. 72 pp.

Lorenzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., de Silva, S.S., Garaway, C.J., Hartmann, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., Sugunan, V.V. & **Swar, D.B.** 2001. Strategic review of enhancements and culture-based fisheries. *In: Aquaculture in the Third Millennium.* R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery and J.R. Arthur (Eds.). p.221-237. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. NACA, Bangkok and FAO, Rome.

Mercier, A., Hidalgo, R.Y. & Hamel, J.-F. 2004. Aquaculture of the Galapagos sea cucumber *Isostichopus fuscus. In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Munro, J.L. & Bell, J.D. 1997. Enhancement of marine fisheries resources. *Reviews in Fisheries Science,* 5(2): 185-222.

Pitt, R. & Duy, N.D.Q. 2004. Sandfish breeding and rearing in Viet Nam. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Purcell, S.W. 2004. Criteria for release strategies and evaluating the restocking of sea cucumbers. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Purcell, S., Gardner, D. & Bell, J. D. 2002. Developing optimal strategies for restocking sandfish: a collaborative project in New Caledonia. *SPC Beche-de-Mer Information Bulletin* 16, 2-4.

Toral-Granda, M.V. & Martinez, P.C. 2004. Population density and fishery impacts on the sea cucumber *(Stichopus fuscus)* in the Galapagos Islands. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Uthicke, S. 2004. Overfishing of holothurians: lessons from the Great Barrier Reef. *In: Advances in sea cucumber aquaculture and management. A.* Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.-F. Hamel and A. Mercier, (Eds.). FAO, Rome. (Present document).

Uthicke, S. & Benzie, J. 2001. Restricted gene flow between *Holothuria scabra* (Echinodermata: Holothuroidea) populations along the North-East Coast of Australia and the Solomon Islands. *Marine Ecology Progress Series,* 216:109-117.

Uthicke, S. & Purcell, S. In press. Preservation of genetic diversity in restocking of the sea cucumber *Holothuria scabra* investigated by allozyme electrophoresis. *Canadian Journal of Fisheries and Aquatic Science.*

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[33] *WorldFish Center, Penang, Malaysia*

[34] *WorldFish Center, Noumea, New Caledonia*

[35] *The information in this paper draws heavily on previous and planned publications by the authors and is presented here in the interests of making the proceedings of the FAO workshop on Advances in Sea Cucumber Aquaculture and Management representative of current research aimed at improving the management of sea cucumbers. These publications are Bell (in press), and a manuscript by J.D. Bell, P. Rothlisberg, J.L. Munro, N.R. Loneragan, W.J. Nash, R.D. Ward and N.L. Andrew entitled "Restocking and Stock Enhancement of Marine Invertebrates " due to be published in Advances in Marine Biology in 2004.*