An Assessment of the Aquaculture Potential of the Caribbean Spiny Lobster, *Panulirus argus*

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ABSTRACT

There is strong demand for spiny lobsters (family Palinuridae) in international seafood markets and this is generating interest in the development of aquaculture for these species. However, a previous assessment of the economic feasibility of commercial land-based culture of a spiny lobster species in the temperate waters of New Zealand indicated that the prospects were poor unless input costs could be reduced and productivity increased dramatically. This earlier assessment recommended that the potential for culturing tropical species of spiny lobsters deserved closer examination, as these species generally have much more rapid growth. Consequently, this present study reviewed information on a tropical species, *Panulirus argus,* from Florida and the Caribbean.

Overall, this review indicates that the prospects for farming *P. argus* profitably are more likely than for temperate spiny lobster species, due to the greater availability of wild seed lobsters and more rapid growth rates. Sea-cage culture or land-based tank culture are probably both feasible, with the former technique being less capital intensive. However, further research and development is required to identify efficient land-based and sea-cage aquaculture systems. Research will also be required to establish the densities and feeding methods for these new grow out systems. A cost effective feed for *P. argus* is probably the most important obstacle to commercial aquaculture development of this lobster on a large scale. Some preliminary work has been done in the Caribbean and in the United States on artificial feeds, and indications are that there is excellent potential for rapid development of a cost effective artificial diet for commercial aquaculture. An important early step toward this goal would be establishing a reference diet that can be used to assess the performance of new diet formulations.

KEY WORDS: Aquaculture, spiny lobster, *Panulirus argus,* Caribbean

INTRODUCTION

In the past few years the early experimental and commercial scale aquaculture of spiny lobsters has begun in a many countries, including Australia, Japan, Croatia, Vietnam, Indonesia, Philippines, Singapore, Taiwan, South Africa, India, Sri Lanka, Tahiti and New Zealand. This development has been driven by the high market value of spiny lobsters and the limited global supply from wild fisheries (FAO 1997).

A previous assessment of the economic feasibility of the commercial land-based culture of spiny lobsters in the temperate waters of New Zealand indicated that the economic prospects were poor unless input costs could be reduced and productivity increased dramatically (Jeffs and Hooker 2000). Consequently, the study recommended that the economic potential of culturing tropical species of spiny lobsters deserved closer examination as these species have more rapid growth.

The tropical species of spiny lobster for which there is the most available aquaculture information and strongest interest in aquaculture is *Panulirus argus* (Ingle and Witham 1968, Tamm 1980, Miller 1983, Ryther et al. 1984, Oesterling and Provenzano 1985. D'Abramo and Conklin 1985, Ryther et al. 1988, Lellis, 1990, 1991, Sandifer 1991, Sandifer 1998). This lobster has an extensive natural range from North Carolina to Brazil and is found throughout the Caribbean (Lellis 1991). The growth rates of this species both in the wild and under captive conditions have been recorded in a number of studies (Travis 1954, Warner et al. 1977, Lellis and Russell 1990, Forcucci et al. 1994, Sharp et al. 2000) and some initial research into artificial diets has been conducted (Pardee and Foster 1992, Sjoken 1999). While there has been very little research into commercial scale hatchery rearing of lobster larvae from eggs (Provenzano 1968, Kittaka 2000), there have been numerous studies into experimental capture of post-larval lobsters, or pueruli, from the wild using a variety of techniques (Little 1977, Gutierrez-Carbonell et al. 1988). This latter source of seed lobsters has considerable potential for extensive commercial scale aquaculture until effective hatchery techniques can be developed.

Therefore, the aim of this study was to review the existing research related to aquaculture of *P. argus* and identify those areas requiring further research and development to expedite the commercial aquaculture of this lobster.

SEED SOURCE

Panulirus argus, like most spiny lobsters, has a long and complex larval development, which proceeds through many stages and is thought to last for at least a year in the wild. Like many species of spiny lobster, the larval biology and ecology of this species is very poorly understood (Yeung and McGowan 1991). Larval development ends in a settling post-larval stage known as the puerulus, which molts to become a benthic dwelling juvenile lobster. Unlike other species of spiny lobster for which there is commercial aquaculture interest, there has been relatively little research into the hatchery production of *P. argus* pueruli (Robertson 1968, Provenzano 1968, Ingle and Witham 1968, Moe 1991, Booth and Kittaka 2000). However, there is a large and accessible supply of pueruli and early juveniles of *P. argus* available for harvest from the wild. Unfortunately, the commercial harvest of the early stages of *P. argus* for aquaculture is currently not permitted anywhere within the natural range of this species, as it is for spiny lobsters in other nations.

Ecological research indicates that pueruli collectors only remove a small proportion of the available pueruli from the wild, and that very large numbers or pueruli and early juveniles are lost to the wild fishery mainly through predation (Butler and Herrnkind 1988, Bannerot et al. 1988, Ryther et al. 1988, Butler and Herrnkind 1989, Forcucci et al. 1994).

Large numbers of wild pueruli and juveniles have been caught for research at a great many locations using a variety of simple and low cost techniques, such as floating and submerged habitats, dip nets, artificial benthic habitats as well as zooplankton nets suspended in tidal currents, towed behind boats or pushed through shallow water (Witham et al. 1964, Calinski and Lyons 1983, Reid et al. 1991, Field and Butler 1994, Phillips and Booth 1994). Suction dredges and benthic trawls have been shown to be an ineffective method of catching early lobsters (Sweat 1968). A great variety of floating and submerged artificial habitats have provided reliable catches of pueruli. Although these artificial habitats have taken many forms, they all provide an abundance of fine scale structural complexity for the pueruli to hide in. These include folded sheets of fibrous material in the Witham collector (Witham et al. 1968), masses of tassels of synthetic fibers in the GuSi collector (Gutierrez-Carbonell et al. 1992) and a modified Phillips (Phillips 1972) collector consisting of a triangular frame of aluminum and PVC sheets holding artificial seaweed (Cruz et al. 1991, 1995).

The geographical and temporal extent of the use of these collection techniques suggest that provided the collectors are placed in suitable areas they will reliably catch pueruli, although the numbers will often vary markedly with location, season and lunar phase (Little 1977, Bannerot et al. 1987, Coton and Nijean 1987, Monterrosa, 1987, Briones-Fourzan and Gutierrez-Carbonell 1988, Butler and Herrnkind 1988, Bannerot et al. 1991, Heatwole et al. 1991, Aguilar et al. 1992, Bannerot et al. 1992, Quinn et al. 1992). For example, nearly 23,000 seed lobsters were taken in less than a year in Antigua using only 28 very small floating collectors (Bannerot et al. 1988). Lellis (1991) estimated that a single floating pueruli collector would trap an average of 300 to 400 pueruli a year in Florida and Antigua. In 185 hours of nighttime sampling using a lantern and a dip net from a dinghy 2,751 pueruli were taken in a shallow bay in Granada (Calinski and Lyons 1983).

The efficiency of these techniques could readily be improved for commercial scale seed lobster collections for aquaculture as they have been in Australia and New Zealand (Jeffs and Hooker 2000). Bannerot et al. (1988) estimated it would cost around US$75,000 to collect around 23,000 pueruli using basic research techniques and including salary for two scientists, scientific equipment, house rental, office and vehicle. Commercial scale collections would be significantly more efficient and could be expected to provide large numbers of pueruli at an estimated cost of US$0.05 to $0.30/seed lobster, which is substantially less than the cost of seed lobsters previously collected for aquaculture in New Zealand (Jeffs and Hooker 2000). Collected pueruli and early juveniles can be transported considerable distances to grow out locations provided they are carefully packed to create the correct conditions (Witham 1970, Lellis and Russell 1990).

GROW OUT

Land-based Culture

Small-scale grow out of lobsters for research in Florida and the Caribbean has been comprised of a variety of seawater systems including flow through, semi-recirculation and full recirculation systems with few problems being encountered (Travis 1954, Ting 1973, Witham 1973, Warner et al. 1977, Quackenbush and Herrnkind 1981, Lipcius and Herrnkind 1982, Ryther et al. 1988, Glaholt 1990, Lellis and Russell 1990, Pardee 1992a, 1992b, Pardee and Foster 1992, Field and Butler 1994, Sjoken 1999, Sharp et al. 2000). Likewise, these studies report lobsters being experimentally grown in a range of tank environments including glass aquaria, as well as fibreglass, plastic and concrete tanks, with and without shelters. Possible differences between tank design and holding conditions have not been explored in detail and may not make a great deal of difference in the growth and mortality of cultured lobsters.

Spiny lobsters, including *P. argus*, are naturally gregarious, however, high tank stocking rates have been shown to inhibit growth in a number of other spiny lobster species (Childress and Herrnkind 1994, Geddes et al. 2001). In addition, limited or poor quality feed is known to induce extensive cannibalism in *P. argus* especially among early captive juveniles. Information of appropriate stocking densities over a range of juvenile sizes for *P. argus* have not been experimentally determined although good growth rates have been obtained at potential commercial densities in experiments designed to test other grow out factors. Increases in stocking densities, equivalent to 266, 533 and 666 juvenile lobsters per m^2 of tank floor were found to produce corresponding decreases in survival due to cannibalism (Díaz-Iglesia et al. 1991). High mortalities of 22-33% over nine weeks at much lower experimental densities of 17.4 and 34.8 juvenile lobsters per m^2 of tank floor were encountered in another study suggesting that improvements in food availability and quality will be a necessary prerequisite for establishing high density grow out systems (Pardee and Foster 1992).

Sea-cage Culture

Only a few studies have investigated the cage culture of *P. argus*, a method that is showing considerable promise in other parts of the world for commercial grow out (Jeffs and James 2001). A 500 m^2 sea-cage was stocked with 15,000 wild caught juvenile lobsters taken from the Brazilian fishery and some growth was recorded after 60 days of holding (Assad et al. 1996). Wild-caught juvenile lobsters (200 - 250 g) apparently performed well in terms of growth when they were stocked into sea-cages at 1.1 per m^2 over 30 days in a shallow canal in the Bahamas (Brown et al. 1995, 1999). Seafloor cages (3 x 3 x 1 m) have also been used in Mexico for holding and feeding juveniles (40 - 81 mm CL) taken from the fishery in an attempt to increase biomass yield (Lozano-Alvarez 1996). However, the overall biomass in every experimental treatment did not increase due to high mortality, probably related to the high stocking densities used (up to 18 kg of biomass per m^2 and up to 88 lobsters per m^2). Other studies have also attempted to increase the biomass of harvested lobsters through impounding and feeding with mixed results (Creswell 1984). Lobsters have also been experimentally cultured from early juveniles in seafloor cages in Puerto Rico (Ting 1973). The cages (0.9 x 1.2 x 1.8 m with 25 x 38 mm plastic coated wire mesh) were stocked at around 25 lobsters per cage and over two years the lobsters grew rapidly to 250 - 300 g in the second year, and to 750-900 g in the third year.

Water Quality Parameters

Water quality and flow rates required for cultured juvenile *P. argus* have not been precisely determined, but they are likely to be very similar to other species of spiny lobster, especially the tropical species *Panulirus cygnus* from Australia (Geddes et al. 2001). The oxygen consumption rates of early juvenile *P. argus* has been recorded and found to increase crepuscularly, during premolt and postmolt, and with increasing water temperature up to 30°C and was at its lowest at a salinity of 35ppt (Brito Pérez and Díaz-Iglesia 1987a, Brito et al. 1991). Mean oxygen consumption at 27°C for large juveniles of 50 - 340g at rest was 0.09 - 0.12 ml (about 0.13 - 0.17 mg)/g body weight/h) and was lethal at some value below 1.95 ml (2.79 mg)/l (Maynard 1960, Buesa 1979). There is also an indication that *P. argus* may avoid waters with high silt loadings, which may be an important consideration in siting aquaculture developments (Herrnkind and Butler 1988).

A number of studies have examined growth rates in relation to water temperature. Maximum growth of early juveniles was found to be at 29 to 30°C, but feed conversion was higher at 27°C (Lellis 1991). Likewise, growth of lobsters from pueruli was greater for animals reared at 30°C than for animals reared at 24, 27, or 33°C, and experimental lobsters at 33°C had lower survival and lower feed conversion than lobsters held at 30°C (Lellis and Russell 1990). Similar results were found in a study in Cuba where the best economic return was estimated to be at a grow out temperature of 28°C (Díaz-Iglesia et al. 1991). Witham (1973), however, found the most rapid growth among juveniles was at lower temperatures of 25 - 27°C, and that they were unable to survive when held at temperatures below 15.6°C or above 32.2°C. He also found that early postlarval lobsters were more likely to die at temperature extremes than larger juveniles.

In the wild early juvenile *P. argus* are frequently found in areas of lowered salinity such as mangroves and upper Florida Bay and are therefore able to withstand low salinity conditions (as low as 19 ppt) as well as fluctuations from ideal (32 - 36 ppt) to as low as 25 ppt (Witham et al. 1968; Buesa 1979, Acosta and Butler 1997, Field and Butler 1994). Tolerance to altered salinities also appears to be greatly reduced by extremes in holding water temperatures (Field and Butler 1994).

Photoperiod and Ablation

A number studies have investigated eyestalk ablation and the manipulation of photoperiod as a means of increasing growth rates of cultured juvenile *P. argus*, however, neither techniques have produced improvements in growth that would be useful for commercial scale grow out (Maynard and Dingle 1963, Maynard and Yager 1968, Maynard and Sallee 1970, Lipcius and Herrnkind 1982, Brito Pérez and Díaz-Iglesia 1983, Quackenbush and Herrnkind 1983, Brito Pérez and Díaz-Iglesia 1987a, 1987b, Díaz-Iglesia et al. 1987, Lipcius and Herrnkind 1987, Brown et al. 1995, 1999).

Diet

Most spiny lobster species perform well in culture when provided with a diet of fresh molluscs (Geddes et al.,2001) and the same pattern has been found for *P. argus*. For example, Ting (1973) found the Caribbean beach clam, *Donax denticulatus*, was an ideal food for captive lobsters. Likewise, a number of other studies have used molluscs, and other seafood material such as fish and prawn waste as food for juvenile lobsters (Assad et al. 1996, Lozano-Alvarez 1996, Díaz-Iglesia et al. 1991, Sjoken 1999). Brine shrimp have been used for experimental culturing of early juvenile lobsters, however, the results indicated that this diet was inadequate as mortalities were high on live brine shrimp. The mortalities were higher again for treatments fed frozen brine shrimp (Pardee 1992a, 1992b, Pardee and Foster 1992). Sjoken (1999) evaluated three artificial diets including a commercial Homarid lobster feed for growth, survival and biomass on juvenile *P. argus* and found that none of the artificial feeds performed nearly as well as the natural food. A range of artificial diets based on soybeans were found to produce good growth in juvenile lobsters, however, mortalities and a control diet were not reported from the study making their effectiveness difficult to assess (Brown et al. 1995, 1999). Lellis (1992) assessed the feasibility of using two reference diets from the American lobster, *Homarus americanus*, for early juveniles of *P. argus* and found that neither was suitable because mortality was high and growth poor. These results confirm other findings which strongly suggest that the metabolism and dietary requirements of spiny lobsters are markedly different to other groups of crustaceans and will require separate development (Crossland 1988).

Growth Rates

A wide range of growth rates of *P. argus* in culture have been reported and are summarised in Figure 1. The growth rates of this species both in the wild and under captive conditions have been recorded in a number of studies (Travis 1954, Olsen and Koblic 1975, Warner et al. 1977, Lellis and Russell 1990, Forcucci et al. 1994, Sharp et al. 2000) and some initial research into artificial diets has been conducted (Pardee and Foster 1992, Sjoken 1999). Very rapid growth rates are achievable in culture, for example male lobsters have been grown from first instar juveniles to 450 g in 12 months and 1.4 kg in two years (Lellis and Russell 1990, Lellis 1991).

Disease

There are few reports of disease in *P. argus*, although a small number of disorders have been reported in spiny lobster species elsewhere. A number of these such as fungal infections are likely to be widespread and capable of rapid proliferation in the preferred temperature range of *P. argus* (Evans and Brock 1994, Porter et al. 2001). More recently a lethal and highly contagious virus has been reported among wild and captive juvenile lobster in the Florida Keys, however, it would seem that this disease can be prevented in land based grow out through relatively simple water treatment systems (T. Matthews and M. Butler IV pers. comm.).

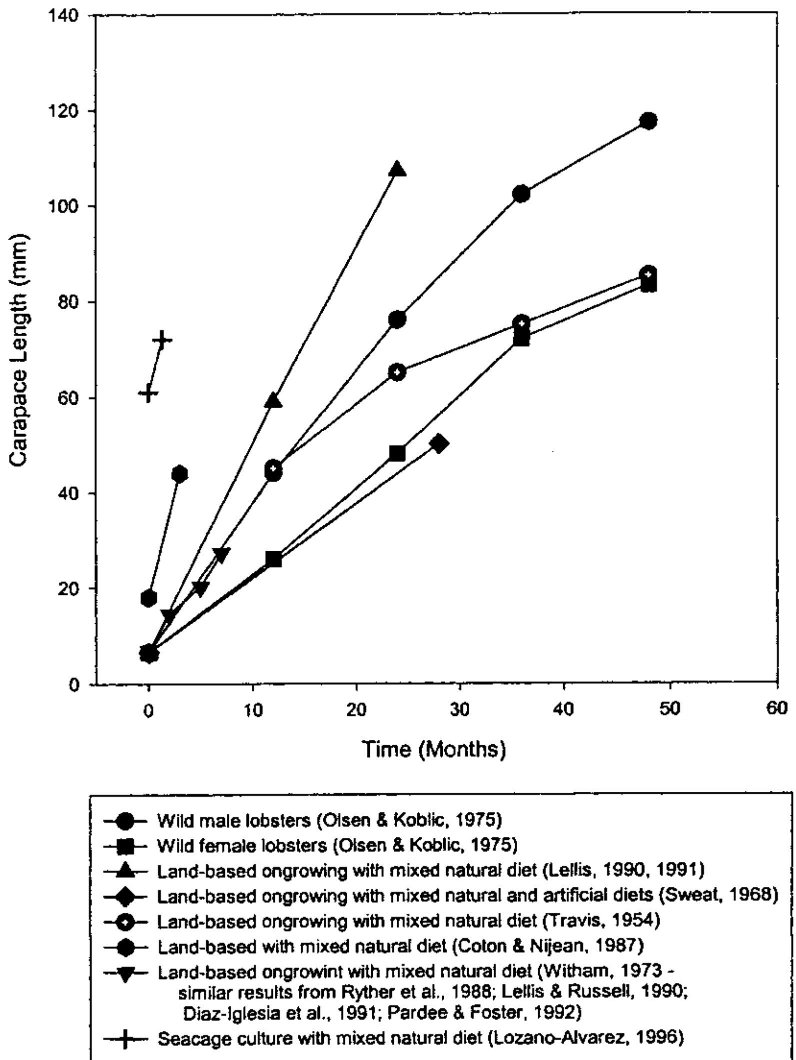

Figure 1. Growth rates for spiny lobster, *Panulirus argus*, under captive conditions. Sizes are reported in carapace length (mm).

DISCUSSION

Overall, this review indicates that the prospects for profitably farming this species of spiny lobster are excellent and far more likely than for temperate species, due to the greater availability of wild seed lobsters and more rapid growth rates (Booth and Kittaka 2000). Sea-cage culture or land-based tank culture are probably both feasible, with the former technique being less capital intensive. However, further research is required to design and develop efficient grow out systems especially in relation to stocking densities, provision of shelters, and feeding regimes. Previous studies have indicated that feed is likely to make up more than 25% of the production cost of cultured spiny lobsters (Jeffs and Hooker 2000). Therefore, a cost-effective feed for *Panulirus argus* is probably the single most important obstacle to large-scale commercial aquaculture development of this species. Some preliminary work has been done in Cuba and in the United States, and there are strong indications that there is excellent potential to rapidly develop an effective artificial diet. A number of commercial diets for spiny lobster are currently available in the USA, however, grow out studies by the authors indicates they are less than optimum. Considerable work is now underway in New Zealand and Australia on artificial grow out diets for different species of spiny lobsters and it is likely that this research will result in advanced formulations that can also be effectively transferred to the culture of *Panulirus argus*.

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