Review of the Turks and Caicos Smithsonian Research Grant
(No. 538-0140-6-00-7069-00)
Project in Mariculture

Requested by the Agency for International Development

February 1988

Conducted by a Panel of the National Research Council
Board on Science and Technology for International Development

EXECUTIVE SUMMARY

The Smithsonian Institution's Marine System's Laboratory (MSL) has established a marine laboratory on Grand Turk Island and is using this facility for a program of research on technology for growing the Caribbean king crab (Mithrax spinosissimus) on a diet of algal turfs. A four-person review team empaneled by the U.S. National Academy of Sciences/National Research Council (NAS/NRC) reviewed the "aquacultural, maricultural, and marine research aspects" of this program in February, 1988, at the request of the US Agency for International Development (AID). The review responded to AID's questions regarding the commercial feasibility of this technology. At the request of the MSL, the review also included assessment of MSL accomplishment of project outputs agreed to by AID and MSL for the period July, 1986-July, 1988.

The panel concluded that commercial feasibility of Mithrax spinosissimus aquaculture based on algal turfs has not been demonstrated by the MSL program and that several years of additional research would be needed before such a demonstration would be possible. The panel noted that 1) no widespread market currently exists for these crabs; 2) existing documentation of commercial interest is very weak; 3) no crabs have yet been grown by MSL staff to a size suitable for existing local markets; and 4) major questions about juvenile mortality remain unanswered.

The panel also concluded that, by the time of the review, MSL (1) had completed one of the project outputs (establishment of a functioning marine laboratory on Grand Turk), (2) had not yet devoted notable attention to a second (preliminary assessment of commercial potential of mariculture systems based on algal turf utilization), and (3) had not

completed the third (assessment of technical feasibility of one or more such mariculture systems). The panel made two recommendations applicable to the present grant period:

1. that the preliminary assessment of commercial potential be completed through a structured approach designed to collect appropriate data and market potential of processed Mithrax as well as the marginal cost effectiveness, and labor efficiencies, of advances in cage designs, maintenance, construction, feeding regimes, algal turf production and the cost of Mithrax processing for market.
2. that crabs currently growing towards potential marketable size (1 kg. wet weight, ca. 120 mm carapace width) be continued in culture until they reach that size, reach sexual maturity, or die.

Since further activity will be needed to unequivocally assess commercial feasibility of algal turf aquaculture, the panel made three recommendations applicable to a subsequent grant period, should there be one. These three recommendations are:

1. that technology currently used by the project be analyzed for potential improvements from the standpoint of systems engineering and appropriateness of the technology for Caribbean fishermen/farmers and/or commercial enterprises;
2. that further research be based on a formal and defined project design that takes full advantage of efficiencies realizable through modern experimental design and statistical analysis; and
3. that further research include a subproject to formally assess issues related to transfer of aquaculture technology developed by MSL to Caribbean fishermen/farmers and/or commercial enterprises.

INTRODUCTION

The U.S. Agency for International Development (AID) requested that the U.S. National Academy of Sciences/National Research Council (NAS/NRC), through the Eoard on Science and Technology for Research and Development (BOSTID),"...conduct a peer review of aquacultural, maricultural and marine research for early commercial exploitation in the Eastern Caribbean, with emphasis on the commercial feasibility of the Caribbean crab species Mithrax spinissimus." An AID research grant to the Smithsonian Institution (Project #538-0140.03B, Grant # 538-0140-6-00-7069-00) for its Marine Systems Laboratory (MSL) had supported work on this project for 18 months of a 24-month contract term at the time of the review in February 1988. That two-year grant of $800,000 was a continuation of research effort by the MSL that had begun in September 1983 and had received $1,931,000 in AID support prior to the $800,000 budget in effect at the time of the BOSTID review.

The NRC appointed a four-person panel to conduct the requested peer review. This team consisted of Dr. John D. Costlow, Director of the Duke University Marine Laboratory, North Carolina, and a specialist in crustacean biology and development; Dr. Charles Adams, a marine resource economist from the University of Florida's Department of Food and Resource Economics; Dr. Paul A. Sandifer, Marine Resources Research Institute,

South Carolina and a specialist in marine aquaculture; and Dr. Dirk Frankenberg, Director of the Marine Sciences Program at the University of North Carolina at Chapel Hill, a specialist in living marine resource utilization. Dr. Frankenberg served as chairman. The panel was provided with background information on Caribbean marine resources, the project on Mithrax spinosissimus (including two prior peer reviews of the MSL research program), and other relevant documentation. The team reviewed that material prior to a visit to Grand Turk Island, Turks and Caicos, British West Indies, the site of current MSL field activities on the project. The site visit to Grand Turk took place February 12-16, 1988.

The BOSTID panel was asked by AID to address one general and four specific issues. These issues and the panel's responses comprise Section I of this report. (See Appendix I, "Problems and Issues to be Addressed by the Team".) In addition, Dr. Walter Adey, Principal Investigator (P.I.) of the research project and Director of the MSL, requested in a letter of February 5, 1988 that the review panel consider the full range of project objectives and assess project performance on the basis of the "Project Objectives, Outputs and Benchmarks" included as Annex A to the grant agreement. (The annex is found under Appendix II.) The panel's response to this request comprises Section II of this report. (Numbering and lettering of material quoted from or in direct reference to Appendix I and II follows the usage of those documents.)

SECTION I - RESPONSE TO ISSUES RAISED BY AID

The analysis which follows corresponds to the "Problems and Issues to be Addressed by the Team" (see Appendix I) as outlined by AID.

> a. The primary issue to be addressed by the team is whether research on Mithrax spinosissimus ever promises to provide commercial returns to private investors or the United States Government, especially given evidence suggesting this animal may, in most adults, suffer a 'terminal molt' preventing most specimens from ever reaching a marketable size.

The panel concludes that it is not currently possible to predict whether continuing research on the algal turf/Mithrax spinosissimus aquaculture system will ever provide commercial returns. This conclusion is based on the fact that even after almost five years of research supported by expenditures of more than $1.7 million in public funds, not one crab has been grown to marketable size in the research project cages. Major questions remain about the nutritional quality of algal turfs, the crab production system, and the economic potential of the aquaculture system. The panel views the major unanswered questions to be:

1. What will be the characteristics of a market for Mithrax spinosissimus? No major market for this species exists now, and even though crab is generally a desirable and valuable seafood product, there is no analytical data showing that a new crab product based on Mithrax will find ready acceptance.

2. Can the Mithrax life cycle be completed under controlled conditions; or, if not, will the wild stocks of egg-bearing females be sufficiently numerous to support a commercially viable aquaculture industry?

The MSL research project has not yet achieved reproduction of Mithrax, although fishermen/farmers from the Dominican Republic have reported reproduction in crabs raised and left behind after the termination of MSL activity there. Credible survey data on wild stocks of egg-bearing females are not available.

3. Can the survival rate of cultured crabs be increased to levels capable of supporting commercially viable aquaculture?

Currently achieved survival rates in the MSL project average 22% from 0-60 days; 23.6% from 60-120 days and 18.5% from 120-300 days. The project estimates that a marketable crab of about 1 kg net weight (ca 120mm carapace width) could be produced at an age of about 400 days. Project staff estimates that survival rates at least double those currently achieved will be necessary for commercial aquaculture although calculations by the team suggest that survival rates of more than 2.5 to 3.5 times as currently achieved will be necessary. The current hypothesis being explored by the research project is that negative interactions between crabs causes mortality, but the review team feels that questions about algal turf nutritional quality and environmental quality inside grow-out boxes have not been fully explored.

4. What controls the size achieved by Mithrax spinosissimus at the molt-to-maturity?

Females of Mithrax spinosissimus molt for the last time when they reach sexual maturity (the molt-to-maturity). This is not a unique feature of M. spinosissimus; female crabs of many species have the same habit. There is some controversy about whether males of M. spinosissimus have the same characteristic. Most majiid crabs that have been studied are thought to

have a terminal molt-to-maturity, but data on the size of mature males in wild populations of M. spinosissimus collected by the MSL project show two or three modes. These modes can be interpreted as evidence for additional molts after sexual maturity. The matter is not settled biologically, but it may be of vital importance to commercial viability of aquaculture because not all mature crabs are of marketable size. Some are, some are not; and the percentage of each varies among populations. The basic biology that controls the size of Mithrax at the molt-to-maturity is not known and is likely to require expensive and time-consuming research. Currently practiced aquaculture technology has not produced a marketable size crab, so the size range of cultured animals at the molt-to-maturity has not been determined. Project staff suggests that different wild populations of Mithrax may differ in the size of the molt-to-maturity, but data to support the hypothesis that these populations are genetically distinct is not available.

5. Can a complete technology for Mithrax spinosissimus aquaculture be transferred to:

a. fishermen/farmers of the Caribbean, or

b. commercial enterprises?

The project has had some experience with technology transfer, but results to date appear to have been mixed. Anecdotal reports by project staff of their Dominican Republic experience suggest transfer will be effective and easy, but letters available from other research teams and at least one commercial undertaking suggest that problems occur when the Smithsonian technology is transferred.

These major problems and an array of minor problems too numerous to mention force the team to conclude that no reliable prediction about commercial returns from this technology can be made without several (three to five) years of additional research at the same level of effort and efficiency.

"b." The second level of issues into which AID requested review team inquiry were as follows:

> 1. Whether research carried out by the MSL in the Eastern Caribbean was scientifically efficacious and efficiently implemented, and
>
> 2. whether MSL focused excessively on 'algal turfs' rather than the animal to be reared commercially, Mithrax sp., thus adversely delaying researchers from observing the more serious obstacles to commercial Mithrax production, such as terminal molt, cannibalism, predation by other crabs, low-survivability, etc.

The team concludes that some of the MSL research has been scientifically efficacious and efficiently implemented. The most notable example is the rapid and apparently problem-free adaptation of algal turf screen culture to field deployment. Other facets of MSL research appear, with the benefit of hindsight, to have been less efficacious and efficient than possible. The team concludes that the major unanswered questions concerning Mithrax biology mentioned above should have been identified and addressed earlier in the project, that economic studies on commercial potential of Mithrax aquaculture should have been conducted, and that preliminary studies currently underway on feeding behavior and survival are flawed by inadequate replication and controls.

The team concludes that the MSL focus on "algal turfs" was inherent to a project designed to assess "the technical feasibility of one or more mariculture systems based on algal turf utilization including culture of Mithrax spinosissimus)" [item 3(a) of Annex A, "Project Objectives, Outputs and Benchmarks"]. It is clear that algal turfs were to be used as the aquacultural food source; it is also clear that important questions still remain of the nutritional quality of the algal turf and the biology of M. spinosissimus. However, the team cannot conclude that "excessive" focus on algal turf prevented collection of this and other needed information.

"c." The third task that AID requested of the panel was to provide advice

> on the merits, or lack thereof, of long-term research on Mithrax spinosissimus, giving clear guidelines ... on whether this species holds greater or lesser promise than other potentially commercial crustaceans or fin-fish commonly found in the Eastern Caribbean.

The panel concludes that "long-term" research on Mithrax spinosissimus will be required if commercially viable aquaculture technology for this species is to be achieved. By the standards of most marine projects, long term (i.e., almost five years) research has already been carried out, and it seems likely that additional research of similar duration (three to five years) will still be necessary before an unequivocal answer can be provided to the question of whether Mithrax aquaculture is commercially viable. The team does not feel comfortable assessing the "merits" of such long-term research since "merit" of any particular project is primarily dependent upon goals and objectives of the program funding it. The panel is not privy to all relevant AID program and U.S. Government goals for this research and

therefore cannot make a rational determination of the merit of long-term research to meeting those goals.

The panel is, however, aware of other potentially commercial crustaceans and fin-fish that might be grown in the Eastern Caribbean. Many of these have the advantage of an established and stable market, but none that we know of can thus far be grown to market size on an exclusive diet of algal turf. These species include such fin-fish as European sea bass, red fish, hybrid striped bass, salt water tilapia, and epinephelid grouper, and such crustaceans as penaeid shrimp, brine shrimp, spiny lobster, and freshwater prawns. All of these species are currently grown on an experimental basis somewhere in the Caribbean region as described in a 1987 USAID/U.S. Department of Commerce report, Caribbean Marine Resources: Opportunities for Economic Development and Management. This report also mentions molluscs such as conch, oysters, top shells, squid, and scallops. Some of these species (sea bass, penaeid shrimp and freshwater prawns) are already produced by aquacultural technology and must therefore be viewed as of clearly greater promise than Mithrax. The other species seem promising to various observers, but, except for existing markets, seem neither more nor less promising than potential Mithrax culture. Experimental rearing of many of these species will continue under various mechanisms of support. Ultimately some effective aquaculture systems will become established. The Mithrax system may be one of them, but it is at an earlier stage of development than many of those mentioned above.

"d." The fourth issue that AID asked the panel to weigh is "whether research on Mithrax can best be carried out by the private or the public

sector." The panel has respectfully declined to offer an opinion on this issue as its members view the question as one of political philosophy rather than of science or technology. The panel does note, however, that there is a long tradition of basic research in the public sector and that issues relating to proprietary interests in research results with commercial potential are among the most contentious currently being faced in academic research administration.

"e." The final request AID made of the panel was for it to indicate

> any other technical or scientific observations of note about this pioneering effort to produce or market the Caribbean King Crab or related marine products.

The panel made five observations of note about the MSL research project, and each led to recommendations. The observations are summarized below:

1. The panel observed that no focused effort had been made to conduct an economic analysis of the commercial potential of Mithrax spinosissimus aquaculture since the admittedly preliminary analysis conducted by the Traverse Group on Antigua and in the Dominican Republic in the summer of 1985. Such an analysis is clearly indicated as one of the agreed-upon outputs of the current grant.

The panel recommends that an economic assessment of the commercial potential of Mithrax culture on algal turfs be conducted before the end of the current contract period. It is suggested that a subcontracted study may be a convenient method to accomplish this task.

2. The panel observes that some controversy exists concerning the ease with which the aquacultural technology developed by the MSL project can be transferred to fishermen/farmers and commercial firms. This controversy seems resolvable if it were consciously explored. Fisheries extension agents such as those found in almost all Sea Grant College programs specialize in transfer of research results to potential users in the fishing industry.

The review panel recommends that an experienced, Spanish speaking fisheries extension agent be employed for a one to two month study of issues involved in transfer of the algal turf-Mithrax aquaculture system to users within the Caribbean fishing industry. The issues to be addressed must include the level of technological development required before fishermen are prepared to invest time and money in establishing a commercial production system.

3. The panel observes that no crabs of 1 kg net weight have yet been produced by the algal turf aquaculture system. Crabs approaching such weight are reported to be in the grow-out boxes now.

The panel recommends that when this project is terminated a procedure be put in place to assure that these remaining crabs are grown out to 1 kg size or sexual maturity or death, whichever comes first. The panel suggests that a contract to a commercial enterprise for this purpose would be a convenient mechanism for accomplishing this recommendation.

4. The panel observes that the technology used in the algal turf-Mithrax aquaculture system has evolved during the project's duration, but has never been studied from the standpoint of integrated systems engineering.

If this project is to be continued for another phase, the panel recommends that a systems engineering analysis of the physical technology (i.e., turf screens, hatch boxes, grow-out boxes, moorings, etc.) be conducted by someone familiar with both systems engineering and the constraints on technology available to fishermen/farmers who might use this system.

5. The panel observes that the current MSL research project does not appear to have a formal research strategy. It does not seem to take full advantage of matrix experimental designs or multivariate statistical analysis of experimental results, nor has it ever determined the nutritional value of algal turfs relative to the published nutritional requirements of decapod crustacea.

If this project is to be continued for another phase, the panel recommends that an expert in experimental design and statistical analysis become involved in project planning so that optimal efficiency can be achieved by this necessarily time-consuming and expensive effort.

SECTION II - EVALUATION OF PROJECT OUTPUTS AND OBJECTIVELY VERIFIABLE INDICATORS

A. Technical Feasibility

Output "(a)":

Assessment of technical feasibility of one or more mariculture systems based on algal turf utilization (including culture of Mithrax spinosissimus).

Indicator (1): Appropriate experiments conducted to evaluate technical feasibility of proposed mariculture systems.

Panel Comment. It is clear that there is only one mariculture system under development, that for Mithrax. No other mariculture "system" (or species) has yet been given any serious consideration or evaluation under this project. Thus, all other review team comments are restricted to the Mithrax system which, as proposed, is based on utilization of algal turf.

Indicator (1)(a): Assess the adequacy of algal turfs as a diet (or partial diet) for the commercial culture of marine species (e.g., can acceptable growth rates and survivorship of organisms be achieved on a diet of algal turfs?)

Panel Comment: Using algal turf screens as the only feed presented to crabs in cages, the P.I. and his team have obtained crab growth rates at Grand Turk comparable to or better than those achieved elsewhere on a similar diet for the first 180 days of rearing. This appears to be the evidence for "acceptable growth rates" Unfortunately, direct comparisons with previous work cannot be made for the post-180 day period, since crabs in the other efforts also were fed macroalgae during this period. Also, average growth rate of Mithrax in nature does not appear to be known, so no comparison with growth in the wild is possible. Further, there does not

appear to be a clear experimental protocol in which algal turf screens are being (or will be) defined or evaluated versus other kinds of feed in replicate grow-out boxes in the field. Thus, while the investigator has clearly demonstrated that the algal turf screens will support crab growth, it is impossible to determine the relative efficacy of the turfs from the field rearing data since there appears to be so little information on growth under other conditions for comparison.

Acceptable survival has not been obtained in the field boxes using the algal turf screens. The research team has arbitrarily ruled out nutrition as a potential cause or contribution to the observed mortality because of the "good" growth rates observed using the algal turf feed. The research team believes that rough wave motion during time of ecdysis and intraspecific aggression are the most likely causes of the mortalities, but no systematic investigation has yet been attempted to isolate the causative factor(s).

The resident team is diligently attempting to address the question of the nutritional adequacy of algal turfs in a study comparing different foods. Unfortunately, this experiment is seriously flawed. Four feed treatments (algal turf alone, macroalgae alone, turf + macroalgae, and turf + macroalgae + conch meat) are being compared, but there is no replication, no controls (e.g., no feed, animal feed only and/or a commercially available feed of known formulation), little apparent standardization of feed amount (the crabs are "fed in excess"), and a very small number of crabs/treatment (five) so that any incidental mortalities could mask important effects. While the study as constituted may provide some preliminary indications of feed suitability if continued long enough for

most of the crabs to molt several times, it is highly unlikely that the researchers will be able to discriminate any differences among or between treatments. The experiment should be redesigned to rigorously examine the hypothesis that algal turfs provide adequate nutrition for crab growth and survival.

Indicator (1)(b): Assess performance of culture candidates (re: molting frequency, growth, hardiness, aggression and reproductive success) across a range of diets and compare results with algal turfs.

Panel Comment: Crab growth and survival (and perhaps "hardiness") are being addressed in a nominal, very superficial manner in experiments underway. Observations are being made on "aggression" (as yet undefined) and molts, but the experimental design is unlikely to allow differences to be identified among treatments (see comments under (1)(a)). A separate small effort is being made in the laboratory to track the individual molt increments of less than ten crabs to determine growth at each ecdysis. Reproductive success is being evaluated only in the sense that wild-caught gravid females are held, eggs allowed to hatch, and then maintained for subsequent spawns. Closure of the life cycle in captivity has been reported by fishermen-culturists at the Buen Hombre (Dominican Republic) site utilized in the former project, but this has not been verified. Actual reproduction (maturation, mating, spawning, hatching) of Mithrax reared in captivity does not appear to be routine and has not yet been accomplished at the Grand Turk laboratory.

Overall, the range of diets being tested is minimal, and it does not include a good no-algae comparison for the turf. Also, no experimentation appears to be underway or planned for the near future to define or evaluate effects of diet in any aspect of crab reproduction. Finally, no data were

evident concerning the biochemical composition and potential nutritive value of algal turfs for comparison with what is currently known about the nutritional requirements of decapod crustaceans. It is not clear if such data will be collected in the future; they certainly should be.

Indicator (2). Physiology and Life History Characteristics.

Indicator (2)(a): Determine physiological tolerances, e.g., salinity and temperature, to assess optimal condition for growth and reproduction.

Panel Comment: This objective has not been accomplished, and there do not appear to be any specific experiments planned to elucidate the ranges of salinity and temperature tolerated by Mithrax. The effect of temperature on growth has not been determined, although the P.I. suggested that different growth rates observed by other research teams were likely the result of temperature effects. The P.I. appears to feel that, from his experience in rearing crabs at several locations in the Caribbean, he can define what salinity and temperature conditions are "optimum" (i.e., satisfactory) for crab growth and reproduction (where reproduction apparently means the production of subsequent fertilized spawns by a mature female captured from the wild) well enough that additional project resources should not be expended on this topic. The review team concurs that "further" expenditure in this area is not warranted.

Indicator (2)(b): Determine whether or not animals undergo terminal molt (through observations of tagged individuals).

Panel Comments: This issue has not been resolved, although the P.I. accepts that female Mithrax have a terminal molt to maturity. No systematic experimentation has yet been undertaken to determine if crabs that have reached sexual maturity molt again. However, all gravid females

brought into the laboratory are tagged so that their spawning history can be recorded. They are also observed for molting and, over time, such observations should provide reasonable evidence relative to the female terminal molt question.

The research team has made a major effort to define, via analysis of morphometric traits, what a "mature male" is and to compare average sizes of adult crabs in geographically separated populations of M. spinosissimus. The MSL team should be commended for this effort. Their results to date should be submitted for extensive peer review by knowledgeable carcinologists, due to the strong differences of opinion among Mithrax researchers. In addition, an appropriate experiment should be conducted to determine if "mature males" (as defined by the MSL team) molt again.

Indicator (2)(c): Determine modal size (weight and carapace length) of population at sexual maturity and compare with marketable size.

Panel Comment: This has not been done yet. However, sufficient size composition data appear to be in hand for at least some populations (see Igleheart, Ruark and Koltes, "Population density and structure of Mithrax spinosissimus" in the MSL "Crab Book") so that modal sizes of mature crabs could be calculated readily. These calculations should be made prior to the end of the current grant. Comparison of modal sizes with "marketable size" may not be very meaningful since market size does not appear to be well defined. Since it appears that the MSL team has defined (somewhat arbitrarily) market size at 1 kg, this is the size that should be used in these comparisons.

Indicator (3): Behavior.

Indicator (3)(a): Determine at what size (if any), and at what densities, animals display aggressive behavior.

Panel Comment: These are being addressed in a preliminary manner at present (see comments under (3)(b)). but it is to become a major emphasis area beginning in April with the arrival of the Ph.D. crab behaviorist. Aggression in the context of this project is not yet defined and presumably such definition, followed by the planning and execution of appropriate experiments, will be among the first activities of the new scientist.

Indicator (3)(b): Determine if, and under what conditions (e.g., food limitation, molting, unequal size distribution, etc.), animals engage in cannibalism;

Panel Comment: Little experimentation has addressed these questions. Observations on aggressive interactions, and any incidents of cannibalism, are being recorded in the laboratory and other studies. Only the lab experiment where crab population density is increased and food (i.e., algal screens) kept constant is designed to specifically address the effects of possible food and space limitation. While this study is replicated and may provide some useful preliminary data, it lacks a no-food control and it may be difficult to partition out the effect of food limitation vs. space. Considerably more experimentation is needed over a broad range of crab sizes. However, a very positive step has been taken by the P.I. in adding a Ph.D. crab behaviorist who should be qualified to properly investigate this topic.

During the review it became apparent that, while the MSL team feels that intraspecific aggression (but not necessarily cannibalism) is likely to be an important cause of mortality in the field grow-out cages, objective data to establish this are lacking. Collection of data pertinent to answering the question, "Is aggression a problem in grow-out of Mithrax spinosissimus?" should be a first priority of the crab behaviorist.

Indicator (4): Parasites and Disease.

Indicator (4)(a): Assess vulnerability of culture population to infection or parasitism under various conditions.

Panel Comment. The MSL team is of the opinion that neither disease nor parasitism have been factors in the culture of Mithrax in cages in clean Caribbean water. However, it appears that only cursory inspections for disease and parasites have been undertaken by the MSL team, due to lack of expertise in these areas, and no specific experiments have been conducted. The P.I. has recently arranged for a private laboratory in the U.S. to conduct post-mortem examinations of crabs which die of unknown causes in the land-based systems. This procedure may yield some useful information.

Indicator (4)(b): Identify possible treatment.

Panel Comment: No treatment has been identified since no disease outbreaks have been noted.

Panel Overall Assessment of Output "a"

1. While some progress has been made in all of the "Objectively Verifiable Indicators," appropriate experiments have not been completed as of this date to allow the technical feasibility of the algal-turf mari-culture system for Mithrax to be evaluated. It appears that the MSL team has concentrated its major effort related to output "a" on field rearing trials, yet high mortality remains a significant unsolved problem in the field cages. Further, it appears highly unlikely that the project will produce any number of "market-size" (1 kg) crabs by the completion date of the current grant. Thus, the central question, "Can market-size mithrax be reared on an algal turf diet in sea cages?," remains unanswered.

2. Observations reported by MSL team members suggest that major mortalities of crabs in sea cages may occur at ecdysis. The researchers have hypothesized that intraspecific aggression and/or rough water motion at time of ecdysis are primarily responsible for the mortalities. These hypotheses are testable, but they have not been examined in any systematic way (see previous comments on aggression studies). One grow-out cage has been placed in a protected area of calm water for comparison with three cages maintained in a more open, rougher-water environment. This effort may provide some indications of the "rough water" effect (along with observations from the beach platform), but it is not adequate to test the hypothesis.

3. While it is highly encouraging that a Ph.D. crab biologist/behaviorist is being added to the research team, it is unfortunate that she will arrive so late in the project. It is also unfortunate that no crustacean mariculturist experienced in other, more proven culture systems has been brought in on a consulting or other basis to assist in the design and evaluation of the grow-out studies, despite the budgetary provisions for this expertise.

B. Economic Considerations

Output "b":

> Preliminary assessment of commercial potential of system(s) identified above, based on collaboration with private sector (e.g., investors, producers, entrepreneurs) and input from recognized research institutions.

Review of "Output b" of the referenced grant "Annex A" (Appendix 11) relates to financial, economic, and commercial feasibility of Mithrax mariculture. The specific output to be reviewed includes (1) an

assessment of the cost effectiveness of the mariculture system to evaluate potential for commercial viability (including labor efficiencies), (2) demonstrated interest by the private sector in investing in production trials, and (3) documentation of results from cost and labor analyses for use in (a) further research and development efforts and (b) the prognosis of commercial viability.

The project was reviewed on the basis of objectively verifiable investor indicators (i.e., output) concerning cost effectiveness, interest, and documentation for use in further R&D analysis. These output are reviewed as follows regarding the "Objectively Verifiable Indicators" for "output b":

> (1) Assessment of the cost-effectiveness of the mariculture system to evaluate potential for commercial viability. This includes analysis of components of the system to determine:
>
> > (a) Labor efficiency of feeding regimes (in the case of Mithrax, algal turf production, and turf feeding to crabs);

Information found in Rubino, et al (1985) indicates that approximately 4-5 man-hours per day could be required to operate a commercial 20-cage Mithrax grow-out operation. MSL staff report in anecdotal fashion that some attention has been given to the labor-requirements of a proposed "commercial" Mithrax cage culture operation. However, no data collection procedure was described and no labor related data were presented to indicate a structured approach toward addressing gains in labor efficiency. As such, no statements could be made by MSL staff as to the marginal improvement in labor efficiency of any achieved or proposed improvements in labor required for producing algal turfs, crab feeding, and related feeding activities.

(1)(b) Labor efficiency of cage construction and maintenance.

The labor requirements of cage and screen construction and maintenance may be an important element in the day to day activities associated with the commercial cage culture of Mithrax. MSL staff did demonstrate that several improvements in cage and screen design have been accomplished that may reduce construction and maintenance labor requirements. These include longer upright stanchions for easier handling in rough water, conical hatchery cage bottoms to better facilitate removal of detritus and use of "Truck Tarp" screens for easier cleaning. MSL staff should be commended for these innovations and the implied resulting labor savings. Other methods are continually being tested to improve the ease of cage and screen handling while in the water and shoreside (i.e., during cleaning). However, no record was presented to the panel that would indicate these savings in labor are being quantified. Materials were presented that documented the labor requirements to build and maintain the current cage and screen designs. However, as with (a), no structured approach is in place to assess marginal labor savings in feeding. Apparently the labor savings in on-going cage and screen design improvements are assumed but not currently quantified in any verifiable manner, with the exception of the proposed use of stamped polypropylene screens.

(1)(c) Cost effectiveness (i.e., durability, availability, and unit cost) of materials used;

MSL staff reported that the approximate fixed cost of constructing a hatchery cage, intermediate cage, grow-out cage, and algal screen was $80, $50, $225, and $8 respectively. These costs were reportedly a function of the costs of materials transportation to Grand Turk and would be different

at each location in the region. The cost estimates presented in Rubino et al (1985) support this notion. MSL staff have provided an itemized assessment of materials costs for each cage and screen. The scale economies of volume purchasing of supplies are not available to MSL and this is recognized. In addition, MSL staff are actively engaged in incorporating new designs into cages and screens that will reportedly reduce the cost of the units and improve durability. The increased use of plastics, PVC, and rubber are examples. The possible use of stamped polypropylene screens would reduce unit screen costs by an estimated 34 percent and extend the screen life from 3 years to indefinite. Previous analyses (Rubino, et al., 1985) suggested that the repair and maintenance of cages and screens represents approximately 50% of estimated operating costs for a 20 cage commercial Mithrax grow-out system. MSL staff did not provide any evidence as to how their cost improvements have generated marginal savings in operating costs (i.e., fewer repairs, longer life, etc.), with the exception of screens. And, as with labor efficiency measurements there appears to be no specific framework to address the issue, other than periodically costing out cages and screens. An assessment of "cost-effectiveness" in input reductions requires an identification of the major production costs (i.e., labor, supplies, fuel, etc.). Without these values, an assessment of the marginal cost effectiveness of design improvements in cages or screens is not possible. The P.I. has recognized that the cost of screens is a major input cost, a cost which may be reduced through amortization. Given that a major variable expense in Mithrax culture, according to previous dated reports, depends upon maintenance, repair, and replacement of screens and cages, there appears to be a lack of appropriate effort being directed toward this topic.

(1)(d) Cost effectiveness of product processing for marketing.

MSL staff have indicated that they currently are not directing any efforts toward addressing this issue on site. However, the P.I. did say that George Clouston, Clouston Foods, has addressed this issue in some manner. It was implied that Mr. Clouston has examined the meat yield of cooked Mithrax and assessed the costs of the processing of Mithrax into a marketable item. However, this information was not provided to the team in written form and can only be considered as anecdotal evidence documenting effort regarding assessing the costs of Mithrax processing.

(2) Demonstrated interest by private sector in investing in production trials.

MSL staff provided the review team with a compilation of letters from several companies and institutions which individually attest to an interest in commercial Mithrax culture or product acquisition for market. These letters were received from:

Grant Stephens, Caribbean Sea Farms, Turks and Caicos;
Dennis Farrier, The Mariculture Institute (TMI);
William Leo Bernard, Caribbean King Crab Corporation;
Burt Hoffpauir, Reef Resources International, Kaplan, Louisiana;
George Day, AAC Development Corp., Omaha, Nebraska;
Carlos O'Kieffe, Trident Marine Corp., Washington, D.C.;
John Keevan Lynch, Pacific Overseas Finance Corp., San Francisco, California.

The correspondence documented a variety of individual interests in commercial Mithrax culture. Caribbean Sea Farms indicated that they had succeeded in receiving a business license from the Executive Council of the Turks and Caicos Islands to operate a "crab farm" on Grand Turk. In addition, Trident Marine Corporation provided evidence of having received approval to undertake a "feasibility study" of the king crab industry in Tobago. Dennis Farrier (TMI) reiterated interest in a major Canadian

seafood purveyor, Clouston Foods, in obtaining supplies of Mithrax for market. Caribbean King Crab Corporation expressed an interest in continuing their own efforts to grow Mithrax to "marketable size" and possibly initiate a market for small crabs as aquarium pets. Reef Resources International and Trident Marine Corp., specifically expressed a need for accurate technical data in order to develop a business plan. AAC Development Corporation and Pacific Overseas Finance Corporation simply provided comments in support of the concept.

These letters do provide evidence as to the interest of a very few firms and institutions regarding the investment potential for commercial Mithrax culture, but do not represent comprehensive and conclusive evidence of investor interest, with the possible exception of Caribbean Sea Farms. The request that this interest be assessed for "investors, producers, and entrepreneurs" does not appear to have been addressed in a conclusive manner, especially with respect to seafood purveyors. However, MSL staff has compiled these documents which imply an interest in the commercial prospects of Mithrax production. A noteable absence from this collection of letters is any correspondence from existing operations in the region, such as Ms. Bartels on Carriacou.

(3) Documentation of results for further R&D efforts and in prognosis of commercial viability.

The panel was not given any indication of specific effort on the part of MSL staff to document how the findings relative to cost effectiveness, labor efficiency, and investor interest can be used to further direct R&D efforts and refine the short term or long term prognosis for economic and commercial viability. In anecdotal fashion, MSL staff have indicated that improvements in cage design, for example, help facilitate research

efforts. However, how these improvements are incorporated into assessments of economic or commercial feasibility has not been indicated.

Summary regarding financial, economic and commercial feasibility

There has been a noteable lack of attention given to successfully achieving in a verifiable manner the stated objectives regarding cost effectiveness and result documentation. There is apparently no structured approach designed to collect appropriate data and make assessments of marginal cost effectiveness, and labor efficiencies of advances in cage designs, maintenance, construction, feeding regimes, and algal turf production. Nor is the expertise available to do so. (A possible exception is the estimated cost and labor savings of using prefabricated polyprophylene algal screens.) In addition, there has been no directed effort at assessing the cost of Mithrax processing for market. These gaps in knowledge are particularly troublesome given that the establishment of commercial feasibility is contingent on accurately identifying production costs and minimizing these costs where possible. These efforts are even more important given that the yield, and the revenue, generated per product unit have yet to be measured. Therefore, attempts to identify and measurably reduce costs where possible is an obvious first step in the assessment of commercial feasibilty.

It could be argued that MSL staff are simply not trained to properly address issues related to financial and commercial feasibility, market analysis, and processing methods. In this case, outside assistance in the form of trained private or academic personnel will likely be required to fully address the stated objectives. An analysis of the financial and

commercial feasibility and market analysis of the proposed system and product would provide benchmark values by which research efforts would/could be directed toward achieving verifiable gains in cost effectiveness, labor efficiency, and, ultimately, expected profits.

C. Establishment of a Laboratory

Output "c":

> Establishment of a functioning marine laboratory on Grand Turk staffed and equipped to conduct applied research in Caribbean Mariculture.

"Objectively Verifiable Indicators" for output "c":

> (1) Permanent staff on site qualified to carry out key experiments as described above.

The relatively small, somewhat unexperienced resident staff have performed admirably in their efforts to carry out the scientific objectives of the project, in spite of the absence of an overall, detailed research plan with appropriate milestones and feedback. Inadequacies, however, were apparent in the disciplinary areas of expertise. Therefore, there was inadequate supervision of the technical staff on a day to day basis.

For example, the resident staff has not included a crustacean/mariculture biologist during the first 18 months of this phase of the project. Thus, a number of critical aspects of the research were not provided the attention they deserved, i.e., significance of terminal molt, sensitivity and stress associated with ecdysis, and high mortality in crabs in 200-400 day grow-out period. Presumably, an experienced crustacean/mariculture biolgist would have recognized the deficiences inherent in the design and implementation of the research (output a, 1-4) and provided for appopriate modification in design.

Similarly, the resident staff has not included anyone knowledgeable in material and engineering design to provide direction in gear development and further modification.

And, finally, none of the resident staff are trained in or familiar with the objectives identified under "output b", e.g., cost-effectiveness, labor efficiency, interest in private sector, and development of further R&D efforts in commercial viability.

The panel further noted the possible negative impacts of the high "turn-over" of staff at all levels, an aspect which may have been aggravated by the inadequacy of the supervision and the absence of a clear design of overall research and logical sequence of events.

(2) Visiting scientists contributing to on-going research through peer review or collaborative efforts.

With the exception of sporadic visits by potential recruits, and this panel peer review visit, there is no evidence the MSL has utilized visiting scientists for the project. Numerous aspects of the research effort could have benefited from input visiting scientists by providing guidance in research areas unfamiliar to the resident staff, by their carrying out specific, short term experiments within the program, and by their providing opportunities for collaboration with specialists in dealing with major problems.

The panel members commented on the isolation of the program and advantages of exploring close association with other Caribbean marine laboratories, perhaps through the Association of Island Marine Labs and the Caribbean Aquaculture Association. MSL could have benefited from initiatives in organizing and hosting periodic workshops or symposia on specific facets of the project. The panel was not given any indication that plans exist for such activities.

(3) Adequate dry lab and wet lab facilities (e.g., running seawater and fresh water, raceways, holding tanks and a land-based hatchery), plus vehicles, communications systems, electrical generators and other equipment required to conduct the necessary research in support of project objectives.

The staff, with special commendation to Kurt Bucholz, Resident Director, have successfully carried out this phase of the program, in spite of numerous obstacles which could easily have deterred less conscientious and determined individuals. It is apparent that uncertain funding, delayed research, complications in changes in local governments, and the relative isolation of the site have posed problems and interfered with the timely completion of physical facilities. The degree to which these factors have interfered with research goals is not clear. Now that the basic physical facilities are available, it would be appropriate to develop a minimum, five-year projection on how the laboratory will be expected to contribute to mariculture research in the Caribbean in future years.

APPENDIX I

Problems and Issues to be Addressed by the Team

a. The primary issue to be addressed by the team is whether research on Mithrax spinosissimus ever promises to provide commercial returns to private investors or the United States' Government, especially given evidence suggesting this animal may, in most adults, suffer a "terminal molt" preventing most specimens from ever reaching a marketable size.

b. Serious questions have been raised by several reports, especially those of Robert Cordover, Clarence P. Idyll & John Caperon, John Ryther, Bob Glazer (Caicos Conch Farm), J. Tarbit, Richard A. Neal and Dee Dee Bartels. These questions suggest two areas requiring further inquiry by the peer panel;

1. Whether the research carried out by the MSL in the Eastern Caribbean was scientifically efficacious and efficiently implemented and

2. whether MSL focussed excessively on "algal turfs" rather than the animal to be reared commercially, Mithrax sp., thus adversely delaying researchers from observing the more serious obstacles to commercial Mithrax production, such as terminal molt, cannibalism, predation by other crabs, low-survivability, etc.

c. The peer panel should advise AID on the merits, or lack thereof, of long-term research on Mithrax spinosissimus, giving clear guidelines to the Agency on whether this species holds greater or lesser promise than other potentially commercial crustaceans or fin-fish commonly found in the Eastern Caribbean.

d. The Panel should also weigh the issue of whether research on Mithrax can be best carried out by the private or the public sector. This issue is important because operatives of the MSL consistently sought out private sector investors in Mithrax, with repeated assurances that MSL possessed technical expertise required to commercially produce crabs. This argument is best laid out in the letter from Dennis Farrier to Mike Huffman, which talks about "farming the sea." The basic question for the Panel is whether it is appropriate for a quasi-government agency like the MSL to promote what is (certainly was) incomplete technical research as being a commercial prospect.

e. The Panel should also indicate in its report any other technical or scientific observations of note about this pioneering effort to produce or market the Caribbean King Crab or related marine products

APPENDIX II

ANNEX A
PROJECT OBJECTIVES OUTPUTS AND BENCHMARKS

1. Project Goal:

To increase rural incomes in the Caribbean through improved management of Marine resources.

2. Purpose:

To identify and develop viable mariculture strategies for the Caribbean which can be implemented by small to medium producers over the near term.

3. Project Outputs:

(a) Assessment of technical feasibility of one or more mariculture systems based on algal turf utilization (including culture of Mithrax Spinosissimus).

(b) Preliminary assessment of commercial potential of system(s) identified above, based on collaboration with private sector (e.g., investors, producers, entrepreneurs) and input from recognized research institutions.

(c) Establishment of a functioning marine laboratory on Grand Turk staffed and equipped to conduct applied research in Caribbean Mariculture.

4. Objectively Verifiable Indicators:

For output a:

(1) Appropriate experiments conducted to evaluate technical viability of proposed mariculture systems. These include experiments on the following:

(a) Assess the adequacy of algal turfs as a diet (or partial diet) for the commercial culture of marine species (e.g., can acceptable growth rates and survivorship of organisms be achieved on a diet of algal turfs?)

(b) Assess performance of culture candidates (re: molting frequency, growth, hardiness, aggression and reproductive success) across a range of diets and compare results with algal turfs.

(2) Physiology and Life History Characteristics

(a)Determine physiological tolerances, e.g., salinity and temperature, to assess optimal conditions for growth and reproduction;

(b) Determine whether or not animals undergo terminal molt (through observations of tagged individuals)

(c) Determine modal size (weight and carapace length) of population at sexual maturity and compare with marketable size

(3) Behavior

(a) Determine at what size (if any), and at what densities, animals display aggressive behavior;

(b) Determine if, and under what conditions (e.g., food limitation, molting, unequal size distribution, etc.), animals engage in cannibalism;

(4) Parasites and Disease

(a) Assess vulnerability of culture population to infection or parasitism under various conditions

(b) Identify possible treatment

For output b:

(1) Assessment of the cost-effectiveness of the mariculture system to evaluate potential for commercial viability. This includes analysis of components of the system to determine:

(a) Labor efficiency of feeding regimes (in the case of mithrax, algal turf production and feeding to crabs);

(b) Labor efficiency of cage construction and maintenance;

(c) Cost-effectiveness (i.e., durability, availability and unit cost) of materials used;

(d) Cost effectiveness of product processing for marketing.

(2) Demonstrated interest by private sector in investing in production trials.

(3) Documentation of results for further R & D efforts and in prognosis of commercial viability.

For Output c

(1) Permanent staff on site qualified to carry out key experiments as described above.

(2) Visiting scientists contributing to ongoing research through peer review or collaborative efforts.

(3) Adequate dry lab and wet lab facilities (e.g., running seawater and fresh water, raceways, holding tanks and a land-based hatchery), plus vehicles, communications systems, electrical generators and other equipment required to conduct the necessary research in support of project objectives.