OCS Study
MMS 99-0019

Development of Methods for Surfgrass (*Phyllospadix* spp.) Restoration Using Early Life History Stages

Final Technical Summary

Final Study Report

U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

OCS Study
MMS 99-0019

Development of Methods for Surfgrass (*Phyllospadix* spp.) Restoration Using Early Life History Stages

Final Technical Summary

Final Technical Report

Authors

Daniel C. Reed
Sally J. Holbrook
Suzanne E. Worcester

Principal Investigators

Prepared under MMS Cooperative
Agreement No. 14-35-0001-30758
by
Coastal Marine Institute
Marine Science Institute
University of California
Santa Barbara, CA 93106

U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

Camarillo
April 1999

Disclaimer

Table of Contents

FINAL TECHNICAL SUMMARY

STUDY TITLE: Coastal Marine Institute Task #12392: Development of Methods for Surfgrass (*Phyllospadix* spp.) Restoration Using Early Life History Stages

REPORT TITLE: Development of Methods for Surfgrass (*Phyllospadix* spp.) Restoration Using Early Life History Stages

CONTRACT NUMBER: 14-35-0001-30758

SPONSORING OCS REGION: Pacific

APPLICABLE PLANNING AREA: Central and Southern California

FISCAL YEAR(S) OF PROJECT FUNDING: FY95, FY96, FY97

COMPLETION DATE OF THE REPORT: January 1999

COST(S): FY 95 - $86,598, FY 96 - $52,649, FY 97 - $82,127

CUMULATIVE PROJECT COST: $221,374

PROJECT MANAGERS: Daniel C. Reed and Sally J. Holbrook

AFFILIATION: University of California, Santa Barbara

ADDRESS: Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, CA 93106

PRINCIPAL INVESTIGATORS: Daniel C. Reed, Sally J. Holbrook, Suzanne E. Worcester

KEY WORDS: ecology, hard bottom, impacts, intertidal, mitigation, *Phyllospadix torreyi*, pipeline installation/removal, restoration, rocky coast, shallow subtidal, Santa Barbara County, surfgrass, seeds, seedlings

BACKGROUND: Surfgrass, *Phyllospadix torreyi*, is an important structure-forming plant in the intertidal and shallow subtidal zones that can be adversely affected by a number of activities associated with offshore oil and gas production. Because of their great ecological importance, surfgrass beds have been designated as environmentally sensitive habitats. This means that adverse impacts on them must be mitigated. Although it is generally agreed that surfgrass restoration is a desirable form of mitigating adverse impacts, to date there has been very little progress in the development of successful restoration techniques. Previous techniques, which have relied on transplanting adult plants, have not been successful and the development of methods that rely on early life stages (i.e., seeds and seedlings) has been hampered by a paucity of information on their ecology. The difficulty this situation poses for future OCS oil-related activities is that an inability to successfully mitigate anticipated losses of surfgrass will not only make it more difficult to obtain permits for new projects, but it hampers the completion of existing projects, which are required to remove pipelines and other structures before a lease can be terminated. This report contains results of studies aimed at obtaining information on the ecology of early life stages of surfgrass that is critical to the development of successful restoration techniques.

DESCRIPTION: Monthly or semiannual surveys of flowering and seed production were done at nine intertidal and five subtidal sites in Santa Barbara County to determine whether natural seed production could be relied on to produce sufficient numbers of seeds and seedlings for restoration programs aimed at mitigating impacts to surfgrass caused by OCS oil and gas related activities. Laboratory studies were used to determine the conditions needed for seed germination and cultivation. Artificial seed collectors were sampled monthly at eight sites to determine whether enhancing the supply of seeds is likely to accelerate the rate of surfgrass recovery.

Abundances of surfgrass seedlings and host plants were recorded in monthly or semiannual surveys at all study sites. Experiments were done in an oscillatory flow tank to determine the relative seed catching abilities of seven species to which surfgrass seedlings are most commonly found. Results from the flow tank were used to predict the types of habitat most conducive to seedling recruitment; these predictions were tested using data collected in the surveys. Laboratory experiments were done to determine whether the application of root growth hormones could be used to stimulate the rate of seedling attachment by accelerating root growth.

Survival of laboratory-reared seedlings outplanted to the field was tested in both intertidal and subtidal habitats. Experiments were done in the subtidal to investigate whether ouplanting seedlings into dense algae affected seedling survivorship. Data obtained from seed collectors and flowering surveys were used to evaluate the degree of seed and seedling predation. Surveys were done at two sites to determine abundances of the most likely predators on seeds and seedlings and laboratory experiments were used to assess whether these potential predators were capable of inflicting significant damage.

SIGNIFICANT CONCLUSIONS: The findings from this study indicated that restoration of surfgrass beds using seeds and seedlings may be feasible. Sufficient numbers of seeds can easily be collected from most populations during most years to supply most restoration needs. Seeds readily germinate in the laboratory, or can be stored for several months and germinated when needed. Laboratory cultivation of large numbers of small seedlings for use in restoration is relatively simple and does not require any sophisticated equipment or facilities. The use of hormones to accelerate root growth and seedling attachment showed high promise in laboratory experiments. Mortality of outplanted seedlings was high in field experiments, but the most likely sources of mortality were identified and potentially can be reduced following additional studies.

STUDY RESULTS: Results from our surveys showed that sufficient numbers of seeds can be collected in any given year to supply the needs of restoration programs designed to mitigate the size of impacts caused by OCS oil and gas related activities. Seeds germinated readily in the laboratory without applying additional stimuli. Storing seeds in cold dark conditions delayed germination and allowed seeds to be stored for up to three months for later use without adverse effects on germination rate. Seedlings grew rapidly in culture following germination.

Results from artificial seed collectors showed that the supply of surfgrass seeds was greatest in the late summer and early fall. The mean number of seeds caught by a collector at a site was not significantly related to flowering at that site. Surfgrass seeds regularly dispersed distances > 20 m. We found no relationship between the number of seeds caught by a collector and its distance from the nearest stand of surfgrass.

Results from the oscillatory flow tank showed that seed attachment varied significantly with both host species and flow velocity. Seed attachment to all species was greatest at a moderate flow; and was reduced significantly at both low and high flow. Data collected from systematic field surveys largely were consistent with results obtained in the laboratory. Species that displayed a high seed catching efficiency in the flow tank generally had more seedlings attached to them in the field. The application of a single dose of a 50:1 mixture of seawater and commercial hormone resulted in a two fold increase in root number and proportional biomass.

High mortality generally was observed in seedlings outplanted to the field. Survivorship was substantially higher in seedlings outplanted to areas where turf algae had been trimmed. High mortality may have resulted in part from dislodgment of seedlings which were outplanted by hand using forceps under conditions of moderate wave surge. Alternate methods of attaching seeds may greatly increase survivorship. Observations from seed collectors and flowering surveys suggested that low seedling survivorship might also have resulted from high rates of predation. On average, we found that nearly half of all seeds and seedlings caught in our collectors had been eaten, while approximately 10% of seed production was lost to predators on the maternal plant. Results from comprehensive surveys suggested that the most likely predators of seeds and seedlings at our study sites were several species of crabs. In a series of laboratory experiments we found two species, the shore crab *Pachygrapsis crassipes* and the kelp crab *Pugettia producta*, inflicted lethal damage to seeds and seedlings that was similar to that observed in our collectors.

STUDY PRODUCTS:

Reed, D.C., S.J. Holbrook, E. Solomon, and M. Anghera. 1998. Studies on germination and root development in the surfgrass *Phyllospadix torreyi*: Implications for habitat restoration. *Aquatic Botany* **62**:71-80.

Blanchette, C.A., S. Worcester, D.C. Reed, and S.J. Holbrook. *In press.* Spatial Variation in Seed Attachment and Recruitment of surfgrass, *Phyllospadix torreyi*. *Marine Ecology Progress Series*.

Holbrook, S.J., D.C., Reed and K. Hansen. *Submitted.* Spatial and temporal patterns of predation on seeds of surfgrass, *Phyllospadix torreyi*.

Reed, D.C., S.J. Holbrook, S. Worcester, C.A. Blanchette. *In prep.* Spatial and temporal patterns of flowering, seed supply and seedling establishment in the surfgrass *Phyllospadix torreyi*.

FINAL STUDY REPORT

INTRODUCTION

Surfgrass, *Phyllospadix torreyi*, is of great ecological importance along open rocky coasts. Among other things, it provides a major nursery habitat for a variety of fishes and invertebrates, some of which have high economic value. Further, since surfgrass also serves as one of the most important sources of biogenic structure in shallow waters it has a strong impact on community structure. Although surfgrass occurs in nearshore coastal waters, it can be adversely affected by a number of activities related to offshore oil and gas production. These include: (1) installation, maintenance, and/or removal of pipelines, piers and other nearshore structures that are used in the production of offshore oil and gas, (2) nearshore activities that involve anchor placement, dredging and discharges, (3) onshore activities that result in erosion or spillage into the nearshore environment, and (4) offshore oil spills. Many of these activities can impact surfgrass throughout its entire depth range. The plants are particularly susceptible to mechanical damage that tears them from the substrate. Populations of surfgrass appear to recover very slowly from such disturbances, and to date there is no proven technology to successfully reattach them on the scale typically required for mitigation. Because surfgrass beds have been designated as environmentally sensitive habitats, adverse impacts on them must be mitigated. Both Santa Barbara County and the State of California (California Coastal Commission, and State Lands Commission) have placed a high priority on research to develop techniques for restoring surfgrass populations damaged by anthropogenic activities.

In Santa Barbara County, the installation of oil pipelines has resulted in local losses of *Phyllospadix torreyi*. The requirement to remove pipelines no longer in use is expected to cause additional losses to surfgrass in the very near future. Although it is generally agreed that surfgrass restoration is a desirable goal for use in mitigation when adverse effects occur, to date there has been very little progress in the development of successful restoration techniques. Attempts at restoring surfgrass populations have relied exclusively on collecting adult plants from undisturbed populations and transplanting them (via glue or epoxy) to the rocky intertidal and shallow subtidal zones of impacted sites. Not only does the collection of established plants cause additional impacts to undisturbed populations, but attaching large numbers of adult plants to the rocky bottom of a wave swept habitat is very difficult and extremely time consuming. It is not surprising that previous surfgrass restoration programs that have used this technique have not been successful in mitigating losses caused by anthropogenic impacts. For instance, in Exxon's restoration project at Corral Canyon in Santa Barbara County the area occupied by transplanted surfgrass showed a continual decline and at the end of the three year study was only 22% of the area that was initially planted. The difficulty this situation poses for future OCS oil-related activities is that an inability to successfully mitigate anticipated losses of surfgrass will not only make it more difficult to obtain permits for new projects, but it hampers the completion of existing projects, which are required to remove pipelines and other structures before a lease can be terminated.

A potentially more cost effective method of restoration that has not been tested involves the use of earlier life stages (seeds or seedlings), which are numerous, easier to obtain, and potentially easier to transplant than adult plants. Moreover, seeds and/or seedlings could be outplanted to desired areas in large numbers without severely impacting existing adult populations. With current funding from Santa Barbara County and the MMS - UC Coastal Marine Institute Program we have been developing methods for restoring damaged surfgrass habitat using early life stages. Our current project is aimed at obtaining the specific information about surfgrass reproduction and early life history needed to develop successful methods of restoration.

BACKGROUND ON SURFGRASS BIOLOGY AND PROBLEMS POSED BY RESTORATION

Phyllospadix is a clonal marine angiosperm that occurs in the lower intertidal and shallow subtidal on moderate to high energy rocky shores. Plants are dioecious, however, the sex ratio of flowering adults is strongly female-biased. There are five species in the genus *Phyllospadix* (Family Potamogetonaceae), two of which occur in Santa Barbara County (*P. torreyi* and *P. scouleri*). The vegetative and flowering shoots of *Phyllospadix* spp. emerge from creeping rhizomes that are solidly attached to the hard substrate by long branching root hairs. The limited information on surfgrass phenology suggests that there is substantial geographic (latitudinal) and local spatial (depth) variation in flowering, pollen production and seed production within and among species. Once fruits (referred to hereafter as seeds following common usage for *Phyllospadix* spp.) are released, their barbed arms attach passively to benthic substrates (usually branched coralline or fleshy red algae, but sometimes established conspecifics) either before or after germination, where they develop (personal observations). If the seedling and host plant survive long enough, rhizome and root formation is sufficient to firmly attach the young plant to the rocky substrate. This is a process that takes months or even longer.

The restriction of *Phyllospadix* spp. to consolidated substrates on exposed shores is unique among seagrasses; all other seagrasses live in soft-sediments of estuaries and other protected habitats. Living in soft sediments in protected waters greatly simplifies the task of transplantation, and successful restoration techniques have been developed for seagrasses that live in these habitats (e.g., *Zostera* and *Thalassia*). Unfortunately, these restoration techniques are not applicable to *Phyllospadix*, which must ultimately attach to a hard rocky substrate in areas of relatively high water motion.

The development of restoration techniques using seeds and seedlings of *Phyllospadix* has been hampered by both insufficient knowledge about the biology and ecology of these early stages as well as a lack of effective outplant techniques. If *Phyllospadix* restoration is to rely on outplanting large numbers of seeds and/or seedlings, it is necessary to have a clear understanding of the spatial and temporal patterns of availability of seeds, how to produce seedlings from seeds (including field collection, laboratory storage and germination), as well as how to attach seeds or seedlings in the natural environment (during restoration) to enhance growth and survivorship. The appropriate times, host types (including natural and artificial host plants), macrohabitat (intertidal, subtidal) and microhabitat locations (tidal pools, benches, boulders, etc.) for outplanting must be determined so that the young stages have the maximum potential for survival. Our ongoing research has provided answers to many of these questions. Below we summarize our work to date that is most relevant to the processes involved in the recovery of damaged surfgrass beds, and to the overall methods and goals of restoration.

RESULTS

Our UC-MMS funded research encompasses three phases of surfgrass restoration: (1) feasibility studies of seed collection, germination and laboratory culture of seeds and seedlings, (2) determining the most critical life history stages that limit successful surfgrass recovery and (3) developing effective methods of surfgrass restoration using the life history stage(s) deemed most likely to limit rates of surfgrass recovery.

Feasibility studies of seed collection, germination and laboratory culture of seeds and seedlings

To better establish the phenology and spatial and temporal patterns of abundance of *Phyllospadix torreyi* in Santa Barbara County we sampled eight permanent intertidal sites and five permanent subtidal study sites twice a year (winter and summer) beginning in December 1994. During each sampling period we assessed percentage cover, leaf density, ratio of male to female flowers, flowering state, seed production, seedling abundance of *Phyllospadix*, and the percentage cover of macroalgae at each site. Much of the work in this phase of our research was funded by Santa Barbara County. UC-MMS Coastal Marine Institute funds have been used to supplement this work, allowing us to examine these variables with much finer temporal resolution. Specifically, we initiated continuous monthly sampling of two of our permanent sites (Hendry's an intertidal site and Mohawk, an adjacent subtidal site) in September, 1995 and intermittent monthly sampling of six intertidal sites (Shoreline, Coal Oil Point, Alegria, Lompoc Landing, Lompoc Landing South and Stairs) using the same protocols as those used in our semi-annual sampling.

When we initially began our studies on surfgrass the conventional wisdom was that natural seed production in *Phyllospadix* was low and that it may not be possible to collect large numbers of seeds required for restoration. Results from our surveys showed that seed production in surfgrass populations of Santa Barbara County is highly variable in space and time (Reed *et al*. in prep). Nonetheless, our data indicate that sufficient numbers of seeds can be collected in any given year to supply the needs of restoration programs designed to mitigate the size of impacts caused by OCS oil- and gas-related activities.

When we began our studies on surfgrass, there was also much uncertainty concerning the specific conditions needed for surfgrass seeds to germinate. In laboratory experiments, we found that germination rates were generally high (at least 70 percent after four weeks) with most seeds displaying a dormant period of at least 14 days (Reed *et al*. 1998). Germination was delayed for at least 82 days without affecting germination rate by placing seeds in cold dark culture conditions. We have also developed the cultivation techniques for growing large numbers of seedlings in the laboratory.

Collectively, this work has important implications for restoration of *Phyllospadix* because it demonstrates that large numbers of seeds can be easily collected in the field, and stored, germinated, and cultivated in laboratory. That the timing of germination can be controlled by inducing dormancy in cold dark conditions is particularly significant because it allows for the synchronous cultivation of large numbers of seedlings from seeds collected at different times and locations and stored for later use.

Seed supply

To determine whether enhancing the supply of seeds alone is likely to accelerate the rate of surfgrass recovery requires a comprehensive understanding of the temporal and spatial variability in seed dispersal and attachment. To this end we monitored rates of seed availability monthly at five sites beginning in September, 1995 using artificial seed collectors. A collector consisted of two pieces of 30.5 cm x 30.5 cm fabric mesh which were fastened to the bolts by a nylon cable tie. The cable tie was cinched around the centers of the square mesh allowing the majority of mesh material to move freely in the surge. Two types of mesh were used to accommodate variability in seed size: 1.7 mm diameter polyester stretch mesh with round openings (polyester netting #9622, Research Nets Inc.) and 1.0 mm diameter mesh with square openings (nylon netting Delta 1004A, Memphis Net and Twine). The fabric diameter of the mesh was similar to that of algae known to facilitate seed attachment and seeds attached to the fabric of the collectors much like they attached to branches of algae.. We disassembled the collectors (the cable ties were cut and the mesh squares were laid out flat) upon retrieval and counted all seeds attached to the mesh. The seed-catching ability of the seed collectors was tested in the oscillating-flow tank along with the most common algal species to which seeds normally attach. Collectors were attached to one of ten permanently fixed bolts in the surfgrass zone at each site. Data on flowering state, seed production and seedling recruitment were also collected at these sites.

We found substantial temporal variability in the delivery of surfgrass seeds. In general, the number of seeds caught by collectors was highest in the winter and lowest during the summer. The maximum number of seeds caught by a collector during a one month interval was 125; during other months the same collector failed to catch any seeds. The delivery of surfgrass seeds was highly variable in space as well. We typically observed as much as an order of magnitude difference in the number of seeds caught by collectors within the same site over the course of a year even though collectors at any given site were located in what appeared to be similar habitat. Our data also indicate that surfgrass seeds regularly disperse distances > 20 m, which is as large as the width of most disturbances to surfgrass beds that result from pipeline installation or removal. We found no relationship between the number of seeds caught by a collector and its distance from the nearest surfgrass: collectors placed within surfgrass beds generally caught fewer seeds than collectors placed > 20 m from surfgrass. This finding suggests that seed emigration from *Phyllospadix* beds is greater than seed retention and that seed dispersal is not likely to prevent the recovery of surfgrass following disturbances resulting from pipeline construction and removal.

Attachment

Our initial observations suggest that seedlings are not randomly distributed in nature. Instead, seedlings tend to be more abundant at certain sites, and they occur more frequently on certain algae. To explore the mechanisms that produce these patterns we experimentally investigated seed attachment to seven algal species and surfgrass under three regimes that simulated natural oscillatory flow in a tank that was specifically designed for this project (Blanchette *et al*. in press). Results showed significant effects of both host species and flow regime. Seed attachment was highest on the intertidal red alga *Chondrocanthus canaliculatus* and the subtidal coralline alga *Lithothrix aspergillum*. Differences in seed attachment among the remaining six species were generally small; on average these plants collected about half as many seeds as *C. canaliculatus* and *L. aspergillum*. Seed attachment to all species was greatest at a moderate flow; and was reduced significantly at both low and high flow. Data collected from systematic field surveys largely were consistent with results obtained in the laboratory. The abundance of host species with high seed-catching abilities explained a significant amount of variation in seedling density at three of four intertidal sites (numbers of seedlings at two subtidal sites were very low and precluded similar analyses). Nonetheless, a substantial amount of variability in seedling recruitment remained unexplained by the abundance and species composition of host plants. The number of seeds that attached to identical seed collectors that we placed in the field was highly variable, both within and among sites, suggesting that variable flow in the surf zone may account for some of the unexplained variability in seedling density.

Survivorship

In spring of 1997 we outplanted 480 laboratory-reared seedlings to three species of algae at an intertidal (Hendry's) and a subtidal (Mohawk) site (n = 160 seedlings per algal species per site) to investigate the effects of host species on seedling survivorship. Seedlings were attached by hooking the arms of the residual fruits on to branches of the various host algae using fine forceps. Very few survivors were observed at either site two weeks after transplanting. Several factors may have contributed to the low survivorship of transplanted seedlings, chief among which was the age of the seedlings when transplanted (~8 months). The fruits of the seedlings had started to decay at the time of transplanting, which likely compromised their ability to remain attached to a host alga, especially given the abrasive whiplash action of adjacent algal fronds. To further explore survivorship of laboratory reared seedlings outplanted to the field we initiated a second transplant experiment in November, 1997. Here we used seedlings that were approximately one month post germination and tested whether seedling survivorship varied on algal hosts whose branches had been clipped to reduce abrasion on seedlings vs. those whose branches were left intact. We observed over 95% mortality within two weeks in seedlings attached to algae whose branches were undisturbed, but less than 50% mortality in seedlings attached to algae whose branches had been clipped. Nonetheless, only about 10% of these seedlings survived to three months and none survived through the harsh winter storms of 1998. In our current MMS-funded project we are testing the degree to which seedling survivorship is influenced by dislodgment, predation, and poor conditions for growth. Data on survivorship obtained from these experiments will provide valuable information on the feasibility of using laboratory-reared seedlings in restoration and of the type of natural and artificial host plants that are most likely to promote successful surfgrass colonization.

Observations from seeds collected in our seed collectors suggested that low seedling survivorship could potentially be caused by high rates of predation on seeds and seedlings

(Holbrook *et al.* in prep). On average, we found that the seeds of nearly half of all fruits and seedlings caught in our collectors had been eaten. Results from comprehensive surveys suggested that the most likely predators of seeds and seedlings at our study sites were several species of crabs. In a series of laboratory experiments we found two species, the shore crab *Pachygrapsis crassipes* and the kelp crab *Pugettia producta* inflicted damage to seeds and seedlings that was similar to that observed in our collectors. In many cases entire seedlings were consumed. These species also proved to be voracious predators on seeds of undehisced fruits protected within the spadix. Damage to seeds and seedlings was inflicted primarily by crabs larger than 10 mm carapace length. Even partial predation by these crabs proved fatal and rendered the seeds incapable of germination. Other species (*Pagarus hirsuitisculus, Idotea spp.* and *Pachycheles rudis)* were found not to inflict significant damage to seeds and seedlings.

Facilitation of root growth

The success of restoration efforts that rely on outplanting laboratory-reared seedlings will be greatly enhanced if seedlings quickly attach to natural rock upon being introduced to the field. Attachment of seedlings is facilitated by rapid root growth. We completed two laboratory experiments to test the effectiveness of biochemical stimulation of root and root hair growth (Reed *et al.* 1998). This involved applications of root growth hormones to recently germinated seedlings. The first experiment tested the effects of hormone concentration on root growth while the second experiment tested the effects of frequency of hormone application on root growth. Root number and proportional biomass (i.e. root mass / total mass) were enhanced by two-fold in seedlings exposed to a 50:1 concentration of hormone:seawater. Higher concentrations of hormone were harmful to seedlings (i.e., they resulted in lower root number, root mass, and total mass relative to controls), whereas lower concentrations of hormone did not have a significant effect on root number and mass. Significant stimulation of root growth was only observed when seedlings were exposed to a single initial application of hormone. Repeated applications either suppressed or had no effect on root development. Collectively these results suggest that it may be possible to facilitate the attachment of transplanted seedlings by a single application of root-inducing hormone immediately prior to transplanting.

In our current MMS-funded project [*An Experimental Evaluation of Methods of Surfgrass (<u>Phyllospadix torreyi</u>) Restoration Using Early Life History Stages*, Reed and Holbrook, PIs] we are testing various outplanting techniques for use in restoration, including whether treating outplanted seedlings with hormones accelerates attachment and increases survivorship in the field.

Publications resulting from this award

Reed, D.C., S.J. Holbrook, E. Solomon, and M. Anghera. 1998. Studies on germination and root development in the surfgrass *Phyllospadix torreyi*: Implications for habitat restoration. *Aquatic Botany* **62**:71-80.

Blanchette, C.A., S. Worcester, D.C. Reed, and S.J. Holbrook. *In press.* Spatial Variation in Seed Attachment and Recruitment of surfgrass, *Phyllospadix torreyi*. Marine Ecology Progress Series.

Holbrook, S.J., D.C., Reed and K. Hansen. *Completed manuscript*. Spatial and temporal patterns of predation on seeds of surfgrass, *Phyllospadix torreyi*.

Reed, D.C., S.J. Holbrook, S. Worcester, C.A. Blanchette. *In prep.* Spatial and temporal patterns of flowering, seed supply and seedling establishment in the surfgrass *Phyllospadix torreyi*.

APPENDICES

APPENDIX I:

FINAL REPORT FOR *"DEVELOPMENT OF A PROPAGATION TECHNIQUE FOR SURFGRASS RESTORATION IN SANTA BARBARA COUNTY,"* PROJECT FUNDED BY SANTA BARBARA COUNTY

Final Report for “Development of a Propagation Technique for Surfgrass Restoration in Santa Barbara County”

Santa Barbara County BC94335

Sally J. Holbrook and Daniel C. Reed, Principal Investigators
Marine Science Institute
U.C. Santa Barbara
Santa Barbara, CA 93106
October 1, 1998

Rationale for project

Surfgrass, *Phyllospadix torreyi,* is of great ecological importance along open rocky coasts. Among other things, it provides a major nursery habitat for a variety of fishes and invertebrates, some of which have high economic value. Further, since surfgrass also serves as one of the most important sources of biogenic structure in shallow waters it has a strong impact on community structure. Although surfgrass occurs in nearshore coastal waters, it can be adversely affected by a number of activities related to offshore oil and gas production. These include: (1) installation, maintenance, and/or removal of pipelines, piers and other nearshore structures that are used in the production of offshore oil and gas, (2) nearshore activities that involve anchor placement, dredging and discharges, (3) onshore activities that result in erosion or spillage into the nearshore environment, and (4) offshore oil spills. Many of these activities can impact surfgrass throughout its entire depth range, which in Santa Barbara County includes the lower intertidal and shallow subtidal up to depths of about 5 – 8 m. The plants are particularly susceptible to mechanical damage that tears them from the substrate. Populations of surfgrass appear to recover very slowly from such disturbances, and to date there is no proven technology to successfully reattach them on the scale typically required for mitigation. Because surfgrass beds have been designated as environmentally sensitive habitats, adverse impacts on them must be mitigated. Both Santa Barbara County and the State of California (California Coastal Commission, and State Lands Commission) have placed a high priority on research to develop techniques for restoring surfgrass populations damaged by anthropogenic activities.

In Santa Barbara County, the installation of oil pipelines has resulted in local losses of *Phyllospadix torreyi*, and the requirement to remove pipelines no longer in use is expected to cause additional losses to surfgrass in the near future. Although it is generally agreed that surfgrass restoration is a desirable goal for use in mitigation when adverse effects occur, to date there has been very little progress in the development of successful restoration techniques. This is due partly to the limited amount of information available about the natural history of surfgrass. Attempts at restoring surfgrass populations have relied exclusively on collecting adult plants from undisturbed populations and transplanting them (via glue or epoxy) to the rocky intertidal and shallow subtidal zones of impacted sites. Not only does the collection of established plants cause additional impacts to undisturbed populations, but attaching large numbers of adult plants to the rocky bottom of a wave swept habitat is very difficult and extremely time consuming. It is not surprising that previous surfgrass restoration programs that have used this technique have not been successful in mitigating losses caused by anthropogenic impacts. For instance, in Exxon's restoration project at Corral Canyon in Santa Barbara County, the area occupied by transplanted surfgrass showed a continual decline and at the end of the three year study was only 22% of the area that was initially planted. The difficulty this situation poses for future oil-related activities is that an inability to successfully mitigate anticipated losses of surfgrass will not only make it more difficult to obtain permits for new projects, but it hampers the completion of existing projects, which are required to remove pipelines and other structures before a lease can be terminated.

A potentially more cost -effective method of restoration that has not been tested involves the use of earlier life stages (seeds or seedlings), which are numerous, easier to obtain, and easier to transplant than adult plants. Moreover, seeds and/or seedlings potentially could be outplanted to desired areas in large numbers without severely impacting existing adult populations. With current funding from Santa Barbara County (as well as the MMS - UC Coastal Marine Institute Program) we have been developing methods for restoring damaged surfgrass habitat using early life stages.

Background of this project

In 1993, as partial mitigation to impacts caused during the construction of its Santa Ynez Unit project, Exxon USA agreed to provide $82,000.00 to fund research focused on developing techniques for restoration of *Phyllospadix*. County staff, in conjunction with staff from the Coastal Commission, State Lands Commission, California Dept. of Fish and Game and Exxon, developed a scope of work and sought a researcher(s) from UC Santa Barbara to conduct the project. This ultimately led to the issuance of SB County Contract #BC94335 "Development of a Propagation Technique for Surfgrass Restoration in Santa Barbara County" to UC Santa Barbara with Sally J. Holbrook and Daniel C. Reed as co-principal investigators. The project entailed a three-year work plan with six tasks, with a start date of March, 1994. On March 24, 1997, the Contract received a no-cost extension until March 31, 1998, with a final report due on October 1, 1998. Because the funds provided by Exxon USA remained in an interest-bearing account during the time period of the project, interest monies in the amount of $14,284 were accumulated. On February 11, 1998, Contract #BC94335 was amended to allocate the interest monies to be used to address several issues regarding reproduction of surfgrass. The final report for the work performed as part of the amended contract is due April 30, 1999; as a result this research will not be considered in any detail here.

This report consists of three parts. First, we briefly summarize information about the biology and life history of surfgrass and problems posed by restoration.

Second, we report progress made for each of the six tasks of SB County Contract #BC94335. Lastly we discuss issues related to mitigation of impacts to surfgrass, including avoidance of impacts, detection of impacts, and strategies for mitigation of impacts.

I. Background on surfgrass biology and problems posed by restoration

Phyllospadix is a clonal marine angiosperm that occurs in the lower intertidal and shallow subtidal on moderate to high energy rocky shores. Plants are dioecious, however, the sex ratio of flowering adults is strongly female-biased. There are five species in the genus *Phyllospadix* (Family Potamogetonaceae), two of which occur in Santa Barbara County (*P. torreyi* and *P. scouleri*). The vegetative and flowering shoots of *Phyllospadix* spp. emerge from creeping rhizomes that are solidly attached to the hard substrate by long branching root hairs. The limited information on surfgrass phenology suggests that there is substantial geographic (latitudinal) and local spatial (depth) variation in flowering, pollen production and seed production within and among species. Once fruits (referred to hereafter as seeds following common usage for *Phyllospadix* spp.) are released, their barbed arms attach passively to benthic substrates (usually branched coralline or fleshy red algae, but sometimes established *Phyllospadix*) either before or after germination, where they develop (Turner 1983, Holbrook and Reed personal observations). If the seedling and host plant survive long enough, rhizome and root formation are sufficient to firmly attach the young plant to the rocky substrate. This is a process that takes months or longer.

The restriction of *Phyllospadix* spp. to consolidated substrates on exposed shores is unique among seagrasses; all other seagrasses live in soft sediments of estuaries and other protected habitats. Living in soft sediments in protected waters greatly simplifies the task of transplantation, and successful restoration techniques have been developed for seagrasses that live in these habitats (e.g., *Zostera* and *Thalassia*). Unfortunately, these restoration techniques are not applicable to *Phyllospadix,* which must ultimately attach to a hard rocky substrate in areas of relatively high water motion.

The development of restoration techniques using seeds and seedlings of *Phyllospadix* has been hampered by both insufficient knowledge about the biology and ecology of these early stages as well as a lack of effective outplant techniques. If *Phyllospadix* restoration is to rely on outplanting large numbers of seeds and/or seedlings, it is necessary to have a clear understanding of the spatial and temporal patterns of availability of seeds, how to produce seedlings from seeds (including field collection, laboratory storage and germination), as well as how to attach seeds or seedlings in the natural environment (during restoration) to enhance growth and survivorship. The appropriate times, host types (including natural and artificial host plants), macrohabitat (intertidal, subtidal) and microhabitat locations (tidal pools, benches, boulders, etc.) for outplanting must be determined so that the young stages have the maximum potential for survival. Criteria must be developed for selection of seeds, especially with regard to sex ratios and genetic diversity. Our ongoing research has provided answers to some of these questions, and we continue to work on others. Below we summarize our work to date relevant to the six tasks of SB County Contract #BC94335.

II. Summary of Results for Tasks 1 - 6 of Contract #BC94335

TASK 1 *We will conduct field surveys to determine natural patterns of spatial and temporal variation in flowering, germination, and growth of Phyllospadix. A total of 6 - 8 permanent study sites (each with Phyllospadix) will be selected between Gaviota and Carpinteria and sampled on a regular basis throughout the study to assess extent and condition of the Phyllospadix beds as well as habitat features. The sites will be chosen to encompass a range of exposures, depths, proximity to freshwater input, and physical conditions. Ultimately we will examine the relationships between these factors and the demographic performance of Phyllospadix. The surveys will provide crucial information on the performance of Phyllospadix under natural conditions. Since these sites will be the source of seeds and mature plants for our laboratory experiments, the surveys will also establish the physical and biological context for these experiments. A subset of the sites will be utilized for outplant experiments (see below) and for intensive study to assess the seed shadow, seed attachment, and spatial and temporal patterns of occurrence of young plants.*

To establish the phenology and spatial and temporal patterns of abundance of *Phyllospadix torreyi* in Santa Barbara County we have been sampling eight permanent intertidal sites and five permanent subtidal sites twice a year (winter and summer) since December, 1994. During each sampling period we assess percentage cover, leaf density, ratio of male to female flowers, flowering state, seed production, seedling abundance of *Phyllospadix*, and the percentage cover of macroalgae at each site. With funding obtained from the Minerals Management Service (see Task 5 below), we sampled more intensively two of the permanent sites (Hendry's, an intertidal site and Mohawk, an adjacent subtidal site). These have been sampled monthly since September, 1995 using the same protocols as those used in our semi-annual sampling. The additional funding also has enabled us to deploy seed traps at eight sites to assess spatial and temporal patterns of abundance of seeds.

The data from our sampling program have revealed that local beds of *Phyllospadix* have some features that are temporally persistent. The first is that beds are not ephemeral; during the past several years none of the beds at our study sites has disappeared, despite severe storms related to the 1997-98 El Nino. With respect to density of leaves, beds tend to thin during the winter storm season and become thicker in the summer. In addition, the phenology of the plants in Santa Barbara County is quite predictable, with flowers first appearing during early to mid-summer and peaking during late summer or early fall. At the sites the average number of seeds per inflorescence (= spadix) ranges from about 12 – 15 with an average of four to six inflorescences per flowering shoot. Most female flowers get fertilized, and seeds mature on the plant for several weeks before being dehisced.

Seeds are most abundant in the environment during fall, and the highest numbers of seedlings occur during the early winter. Depth of sand in surfgrass beds tends to be greatest in winter, and seeds and seedlings can be buried, leading to mortality. Finally, females greatly outnumber males at all of the sites sampled. Our sampling documented substantial variation both among sites and among years in virtually every life history feature assessed. In particular, flowering (and thus seed production) varies over an order of magnitude among sites within any particular year, and a site with abundant flower production in one year can have low flowering the next. Beds tend to be thinner in the subtidal zone than the intertidal, but at any particular time sites within the same habitat type can differ by a factor of five times in the number of leaves per square meter.

To determine whether enhancing the supply of seeds alone is likely to accelerate the rate of surfgrass recovery requires a comprehensive understanding of the temporal and spatial variability in seed dispersal and attachment. To this end we have been monitoring rates of seed availability at least monthly at two sites, Hendry's and Mohawk, beginning in September, 1995 using traps made of nylon mesh (we designed the traps specifically for catching surfgrass seeds and we found them to be very effective in laboratory and field trials). Beginning in June, 1996 we began collecting seed trap data at six additional intertidal sites in Santa Barbara County: three south of Pt. Conception (Shoreline, Devereux, and Alegria) and three north of Pt. Conception (South Lompoc Landing, Lompoc Landing, and Stairs). Every month traps are placed at and retrieved from ten locations at each of the sites. Data on flowering state, seed production and seedling recruitment are also collected at these sites.

The results of our studies of seeds indicate that there is substantial temporal variability in the delivery of surfgrass seeds. In general, the number of seeds caught by traps was highest in the winter and lowest during the summer. The most seeds caught by a trap during a one month interval was 125; during other months the same trap failed to catch any seeds. The delivery of surfgrass seeds is highly variable in space as well. We typically observed as much as an order of magnitude difference in the number of seeds caught by traps within the same site over the course of a year even though traps at any given site are located in what appears to be similar habitat. Data from Alegria showed that surfgrass seeds regularly disperse distances > 20 m, which is as large as the width of most disturbances to surfgrass beds that result from pipeline installation or removal. We see no relationship between the number of seeds caught by a trap and its distance from surfgrass: traps placed within surfgrass beds often caught fewer seeds than traps placed • 20 m from surfgrass. These data suggest that seed emigration from *Phyllospadix* beds is greater than seed retention and that seed dispersal is not likely to limit the recovery of surfgrass following disturbances resulting from pipeline construction and removal.

Some other key findings of our multi-year sampling program have been that flowering and therefore seed production are not uncommon as was previously thought, and therefore obtaining seeds for restoration purposes would not be difficult.

In addition, the variability expressed in life history features among the beds in Santa Barbara County illustrates the need to assess both potential anthropogenic impacts to beds as well as success of any restoration efforts in an appropriate context.

We are currently preparing a manuscript based on this sampling effort that will explore spatial and temporal patterns of variation in life history features of surfgrass. A draft will be available by early 1999.

TASK 2 *Using laboratory propagation techniques, we will examine the effects of several factors (e.g., light, temperature, water motion) on germination of seeds and on early growth. We anticipate using seeds collected from several of our field sites for these experiments. These studies will also focus on the processes that influence the attachment of seeds to specific substrates, and we plan to quantify the efficiency of attachment and subsequent early growth on a variety of natural and artificial substrates. All laboratory studies will be conducted in sea water aquaria and/or culture facilities at UC Santa Barbara.*

When we initially began our studies on surfgrass the conventional wisdom was that natural seed production in *Phyllospadix* was often low and that it may not be possible to collect large numbers of seeds required for restoration. Moreover, there was much uncertainty concerning the specific conditions needed for surfgrass seeds to germinate. Previous workers had experienced difficulty in germinating the seeds under laboratory conditions. We found that seed production is actually very high in Santa Barbara County populations and we have developed methods for collecting and storing large numbers of seeds. In our laboratory experiments germination rates were generally high (at least 70 percent after four weeks) with most seeds displaying a dormant period of at least 14 days. Germination could be delayed for at least 82 days without affecting germination rate by placing seeds in cold dark culture conditions. We have also developed the cultivation techniques for growing large numbers of seedlings in the laboratory. Collectively, this work has important implications for restoration of *Phyllospadix* because it demonstrates that large numbers of seeds can readily be collected in the field, and stored, germinated, and cultivated in the laboratory. That the timing of germination can be controlled by inducing dormancy in cold dark conditions is particularly significant because it allows for the synchronous cultivation of large numbers of seedlings from seeds collected at different times and locations and stored for later use. Our findings on seed germination in *Phyllospadix* form the basis of a manuscript that will be published soon in *Botanica Marina*. A copy of this paper is included with this report.

The success of restoration efforts that rely on outplanting laboratory-reared seedlings will be greatly enhanced if seedlings quickly attach to natural rock upon being introduced to the field. Attachment of seedlings is facilitated by rapid root growth. We completed two laboratory experiments to test the effectiveness of biochemical stimulation of root and root hair growth. This involved applications of root growth hormones to recently germinated seedlings. The first experiment tested the effects of hormone concentration on root growth while the second experiment tested the effects of frequency of hormone application on root growth. Root number and proportional biomass (i.e. root mass / total mass) was enhanced by two fold in seedlings exposed to a 50:1 concentration of hormone:seawater. Higher concentrations of hormone were harmful to seedlings (i.e., they resulted in lower root number, root mass, and total mass relative to controls), whereas lower concentrations of hormone did not have a significant effect on root number and mass. Significant stimulation of root growth was only observed when seedlings were exposed to a single initial application of hormone. Repeated applications either suppressed or had no effect on root development. Collectively these results suggest that it may be possible to facilitate the attachment of transplanted seedlings by a single application of root-inducing hormone immediately prior to transplanting. These results have been included in the manuscript that is in press in *Botanica Marina*.

In order to determine the best strategy for restoration by outplanting young stages of surfgrass, we studied natural patterns of occurrence of seedlings on hosts, and we conducted laboratory tests to explore whether there are differences among hosts in the ability to catch or retain seeds. Our initial observations suggested that seedlings are not randomly distributed in nature. Instead, seedlings tend to be more abundant at certain sites, and they occur more frequently on certain algae. To explore the mechanisms that produce these patterns we experimentally investigated seed attachment under three regimes that simulated natural oscillatory flow in a tank that was specifically designed for this project. In these studies we tested attachment to seven algal species, surfgrass, and our artificial seed traps made of nylon mesh. Results showed significant effects of both host species and flow regime. Seed attachment was highest on the intertidal red alga *Chondrocanthus canaliculatus* and the subtidal coralline alga *Lithothrix aspergillum*. Differences in seed attachment among the remaining six species and the nylon seed traps were generally small; on average these substrates collected about half as many seeds as *C. canaliculatus* and *L. aspergillum*. Seed attachment to all species and seed traps was greatest at a moderate flow; and was reduced significantly at both low and high flow. Data collected from systematic field surveys largely were consistent with results obtained in the laboratory. The abundance of species with high seed-catching abilities explained a significant amount of variation in seedling density at three of four intertidal sites (numbers of seedlings at two subtidal sites were very low and precluded similar analyses). Nonetheless, a substantial amount of variability in seedling recruitment remained unexplained by the abundance and species composition of host plants. The number of seeds that attached to identical seed traps that we placed in the field was highly variable, both within and among sites, suggesting that variable flow in the surf zone may account for some of the unexplained variability in seedling density. These findings are the subject of a manuscript that is currently in review in *Marine Ecology Progress Series*. A copy of this manuscript is included in this report.

TASK 3 *Seedlings germinated in the laboratory (see Task 2) will be outplanted to the field and monitored for at least one year. We anticipate outplanting laboratory-germinated seedlings in the context of a multifactorial experiment to test the effects on subsequent growth and survival of (a) seedling age (or size), (b) attachment substrate, (c) site/parental source (of seed), (d) location of transplant (depth, exposure, etc.), and other factors as appropriate. We will compare the growth and survival of the outplants with naturally-produced seedlings to the extent possible.*

We have conducted two different outplant experiments. In spring of 1997 we outplanted 480 laboratory-reared seedlings to three species of algae at an intertidal (Hendry's) and a subtidal (Mohawk) site (n = 160 seedlings per algal species per site) to investigate the effects of host species on seedling survivorship. Seedlings were attached by hooking the arms of the residual fruits onto branches of the various host algae using fine forceps. Very few survivors were observed at either site two weeks after transplanting. Several factors may have contributed to the low survivorship of transplanted seedlings, chief among which was the age of the seedlings when transplanted (~8 months). The fruits of the seedlings had started to senesce at the time of transplanting, which likely compromised their ability to remain attached to a host alga, especially given the abrasive whiplash action of adjacent algal fronds.

To further explore survivorship of laboratory-reared seedlings outplanted to the field we initiated a second transplant experiment in November, 1997. In this experiment we used seedlings that were approximately one month post-germination. We tested whether seedling survivorship varied on algal hosts whose branches had been clipped to reduce abrasion on seedlings vs. those whose branches were left intact vs. nylon mesh glued to the bottom. We observed over 95% mortality within two weeks in seedlings attached to algae whose branches were unclipped, but less than 50% mortality in seedlings attached to algae whose branches had been clipped. Even higher survivorship was observed on nylon mesh. Nonetheless, only about 10% of these seedlings survived to three months and none survived through the harsh winter storms of 1998.

With funding obtained from the Minerals Management Service (see Task 5 below) we are conducting additional experiments (during late 1998 and 1999) to test the degree to which seedling survivorship is influenced by dislodgment, predation, and poor conditions for growth. Data on survivorship obtained from these experiments will provide valuable information on the feasibility of using laboratory-reared seedlings in restoration and of the type of natural and artificial host plants that are most likely to promote successful surfgrass colonization.

Observations from seeds collected in our seed traps suggest that low seedling survivorship could potentially be caused by high rates of predation on seeds and seedlings. On average, we find that the seeds of nearly half of all fruits and seedlings caught in our traps have been eaten. Results from comprehensive surveys suggest that the most likely predators of seeds and seedlings at our study sites are several species of crabs. In a series of laboratory experiments we found two species, the shore crab *Pachygrapsis crassipes* and the kelp crab *Pugettia producta*, inflicted damage to seeds and seedlings that was similar to that observed on seeds caught in our traps. In many cases entire seedlings were consumed. These crab species also proved to be voracious predators on seeds of undehisced fruits protected within the spadix. Damage to seeds and seedlings was inflicted primarily by crabs larger than 15 mm carapace length. Even partial predation by these crabs proved fatal and rendered the seeds incapable of germination. With funding obtained from the Minerals Management Service, we are conducting field experiments to further quantify the effects of predation on seed production, seed supply, and seedling survival.

TASK 4 *We will conduct flowering studies in the laboratory using mature plants to explore the effect of light regimes and water temperature on the process of flowering, and to assess whether seeds for outplanting can be obtained in the laboratory. Mature plants will be collected from several of our established field sites (Task 1) and maintained in flow-through sea water aquaria in the laboratory. Existing evidence suggests that there may be substantial variation in flowering among localities, and our laboratory experiments will be designed to help explain this pattern.*

When we started our work on surfgrass, there were reports that flowering appeared rare in some populations of *Phyllospadix*. In the absence of data for Santa Barbara County populations, it seemed reasonable that one task for restoration would be to determine methods to enhance flowering (perhaps in laboratory culture using adult plants) and thus produce the quantities of seeds needed for outplanting. However, we found almost immediately that flowering is not rare in local populations of surfgrass. However, it is highly seasonal and very variable within and among sites. Further, in pilot laboratory investigations we found that culture of large, flowering specimens of surfgrass is difficult and likely to be very costly over the long run because the plants become fouled very easily. [The problem of fouling is easily overcome in culture of the much smaller seeds and seedlings.] For these reasons, we concluded that devoting efforts to culturing adult plants in the laboratory only to obtain seeds is not as productive a research direction as understanding the causes of variation in flowering in field populations. Therefore, we focused most of our effort on documenting more carefully the spatial and temporal patterns of variation in flowering and seed production, and understanding the causes. Thus far we have found no evidence that extrinsic factors such as fouling of leaves by epiphytic algae or the degree of seasonal inundation by sand cause variation in flowering. One major issue raised by these studies of flowering is our observation that areas with very low pollen production (as evidenced by rarity in male flowers) can have extremely high seed production. This is puzzling since male flowers are needed for pollination. It is possible that many *Phyllospadix* seeds may be the product of asexual rather than sexual reproduction. If so, this raises questions about the genetic composition of local populations. Knowledge of the frequency of asexual reproduction is of critical importance to the design of restoration strategies because it is important to restore in a way that maintains genetic variation. Currently, we are investigating the genetics of Santa Barbara County populations of surfgrass using the interest monies from this contract.

TASK 5 *We will pursue matching funds for the project. We have already received $17,000.00 from the Southern California Educational Initiative, and we expect to apply to Sea Grant and to the Southern California Educational Initiative for additional funds. Receipt of matching funds will allow us to devote more effort to the tasks described above, as well as to extend the time span of the project and permit additional tasks to be completed.*

Task 5 is complete. We were awarded matching funds from the MMS-UC Coastal Marine Institute in the form of a three-year grant ["Development of Methods for Surfgrass (*Phyllospadix* spp.) Restoration Using Early Life History Stages"]. This project was funded from July 1, 1995 for a three-year period, for $210,514. The University of California contributed matching funds for this project for salaries (including benefits and indirect costs) for Professional Researchers, a technician and to support a graduate student. We have recently received additional funding for a continuation of the research from the MMS-UC Coastal Marine Institute. This new project, entitled "An Experimental Evaluation of Methods of Surfgrass (*Phyllospadix*) Restoration Using Early Life History Stages" has been funded for a 30-month period starting July 1, 1998, for a total of $168,883 (with matching funds from the University of California for salaries and graduate student support). The major goal of the newly-funded project is to test restoration strategies on a larger spatial scale than we have to date, using outplants of seeds and seedlings to sites along the Santa Barbara coastline. We will be outplanting our first sets of seeds and seedlings later this fall.

TASK 6 *A brief budget and progress report will be provided to William Douros at the end of month 5 (August) and month 11 (February) of each project year. A final report on propagation and restoration techniques of Phyllospadix will be submitted to the County of Santa Barbara within six months of the ending date of this project (by Sept. 30, 1997). In addition, theses and research papers that result from the research will be provided.*

This task is complete to date. Two papers are attached to this report, and list of presentations given at conferences and workshops is given below. We will continue to provide copies of all research results that we publish in the scientific literature.

Publications and manuscripts:

Reed, D.C., SJ. Holbrook, E. Solomon, and M. Anghera. Studies on germination and root development in the surfgrass *Phyllospadix torreyi*: Implications for habitat restoration. In press, *Botanica Marina*

Blanchette, C. A., S. Worcester, D. C. Reed, and S. J. Holbrook. Spatial Variation in Seed Attachment and Recruitment of surfgrass, *Phyllospadix torreyi*. In review, *Marine Ecology Progress Series*

Presentations:

We have made a number of presentations during the past several years including:

Worcester, S.E. "Dispersal and Recruitment Processes in Marine and Estuarine Organisms along the California Coast", Calif. State University, Monterey, April, 1996

Solomon, E. "Interactions Among Seagrass Epiphytes and their Consequences for the Host Plant", Western Society of Naturalists Annual Meeting, La Paz, Mexico, January, 1997

Blanchette, C. "Taking Biomechanics to the Field: Pattern and Process in Wave-swept Plant Communities", UC Santa Cruz, February, 1997

Blanchette, C. A., S. Worcester, D. C. Reed, and S. J. Holbrook. "Facilitation of Surfgrass Recruitment by Host Algal Morphology and Water Flow", Fourth International Temperate Reef Symposium, Santiago, Chile, July, 1997

Blanchette, C. "Opening the Black Box: Exposing the Coupling between Coastal and Oceanic Ecosystems", Calif. State University, Northridge, March, 1988

Reed, D.C. and S.J. Holbrook. "Restoration of Surfgrass Using Early Life History Stages", Minerals Management Service, Camarillo, CA, April 1998

Reed, D.C. "Research on Restoration Strategies for Surfgrass", The Chancellor's Community Breakfast, Santa Barbara, CA

III. Recommendations for Mitigation

Although our studies of the biology of *Phyllospadix* and strategies for restoration using early life stages are not yet complete, below we review some of our findings and conclusions regarding both prevention and remediation of anthropogenic impacts on surfgrass. Our ongoing work on survivorship and our tests of artificial host substrates will provide more definitive insight into the practicality of using seeds and seedlings for restoration. Below we discuss three major themes regarding impacts – impact avoidance, impact assessment and population recovery.

Avoidance of Impacts

The results of our studies have reinforced the concept that the best mitigation is to avoid impacts to *Phyllospadix* beds because natural recovery is likely to be slow. We have yet to see instances of wholesale seedling establishment that lasts more than a few months despite sampling at a variety of sites over 4 years. Although production of seeds in local populations can be extremely high, we have documented little natural recruitment (seedlings persisting a year or more) via sexual reproduction. The reasons for the low levels of recruitment differ between the intertidal and subtidal zones. In the intertidal zone, many seedlings occur but mortality of these seedlings during their first few months is very high. In the subtidal zone, few seedlings occur naturally, although mortality in this habitat may be lower than in the intertidal. [Restoration attempts may be more successful in the subtidal as well – see below.] Together these observations indicate that following disturbances to surfgrass meadows, populations are not especially likely to rapidly re-establish on their own by sexual reproduction, even if adult reproductive plants occur in the vicinity to provide propagules to the disturbed areas. Rather, natural re-establishment is more likely to occur by slow clonal expansion of whatever plants remain following the disturbance.

Despite the fact that we have not documented large recruitment events during the past four years, rare events of recruitment probably do happen on longer time scales, much like the situation for long-lived trees like oaks and redwoods. The large investment in sexual reproduction made by *Phyllospadix* suggest that there are undoubtedly times that recruitment from seeds is important.

Small disturbances that result in holes in surfgrass beds should recover naturally by vegetative growth, but this process will be slow. Research conducted by Stewart (1989) indicates that a single rhizome could elongate a distance of about a meter in two years, and that small (< 1 m diameter) patches of surfgrass require several years to reach that size.

Lastly, anthropogenic impacts should be avoided because no restoration technique will be rapid. The reasons for this are that establishment and growth of surfgrass plants are very slow, and there is an annual cycle of reproduction. Thus, if early life stages are used, seeds are only available once each year. Under natural conditions, it takes a seedling about a year to attach to bottom substrate once it snags on a host plant. Lateral growth of rhizomes once they attach to the bottom is on the order of a few tens of centimeters per year. Even if early growth can be speeded up by hormone treatment (which our research suggests is possible), it is likely that restoration and recovery would take years.

Assessment of Impacts to Surfgrass Beds and of Recovery

Assessing impacts, and also assessing success of natural recovery or mitigation efforts, will be challenging because features of surfgrass beds are quite variable in space and time. Our surveys revealed substantial seasonal change, plus extremely large variation in attributes such as sex ratio, flowering and seed production, density of plants and so forth among nearby (even adjacent) sites. Therefore, it will be necessary to sample before and after the time of occurrence of potential anthropogenic impacts. Further, any comparison sites need to be chosen with care, and a range of different variables to assess condition of the bed should be utilized. Time periods of sampling will need to be long (years rather than months) to take into account the slow growth of surfgrass.

Recovery of Surfgrass Beds and Potential for Mitigation

Regardless of whether restoration attempts are planned to mitigate possible damage, anthropogenic activities in surfgrass beds should be conducted so as to retain the natural habitat for the plants, which is exposed hard substrate. Surfgrass plants grow on benches and boulder fields, but in order to support persistent populations of surfgrass boulder fields must have stable rocks that do not roll during winter storms. Disturbances that destabilize boulder fields will probably result in loss of surfgrass, even if the plants themselves are not initially damaged. Disturbances that result in long-term (or permanent) burial of the hard substrate in an area will preclude recovery. No amount of elapsed time since disturbance will compensate for destruction or covering of the necessary hard substrate for *Phyllospadix*. In addition, in our surveys we have never found seedlings establishing in the absence of host plants – either algae or adult surfgrass. Disturbances that result in the loss of host plants will minimize the potential for natural recovery, at least in the short term.

Restoration efforts have the potential to speed recovery of damaged surfgrass beds. Our surveys revealed that flowering plants were much more abundant than thought previously and many seeds are produced and are available in the environment. However, the issues posed for restoration are somewhat different in the intertidal compared to the subtidal zone. For instance, regarding the intertidal zone, seed availability is quite high. Seeds are transported easily into the intertidal, and over small spatial scales seed supply to disturbed intertidal areas is potentially not a problem as long as some reproductive plants are nearby. However, attachment of seeds in the intertidal is very variable independent of host availability, possibly because of small scale variation in flows, so enhancing seed attachment via outplanting may be a more reliable way of getting seeds to impacted intertidal areas. Just putting out hosts and waiting for passive seed transport could work in the intertidal zone but results would likely be enhanced if seeds were outplanted as well.

By contrast, seed availability is much lower in the subtidal zone. Recovery of impacted subtidal areas would benefit from the addition of outplanted seeds, regardless of whether suitable host plants are available. Passive attachment of naturally-occurring seeds onto natural or artificial host substrates in the subtidal zone would not be likely to have the desired result. Since most local populations of surfgrass occur primarily in the subtidal, restoration will likely necessitate augmentation of the natural supply of seeds and/or seedlings.

The quality of seeds – whether naturally-occurring or outplanted – is a major issue for restoration. Our surveys have revealed that many seeds are damaged by predators, and predators may be the major source of seed/seedling mortality. It will be necessary to harvest seeds before predators get them. Seeds should be harvested directly from plants, rather than caught after they are released into the environment. This prevents seed predation, which in Santa Barbara County appears to occur mainly after release. Further, our work has shown that seeds are easy to collect in large numbers while on the plants and they are easy to culture and mature to the desired stage in the laboratory.

Other factors related to seed quality are the genetic composition and gender of seeds and seedlings. We are actively exploring these issues now. Once we know more about the genetics of *Phyllospadix* it will be possible to assess whether some populations are more “valuable” than others (assuming the value lies in genetic variation and a balanced sex ratio). This information would be crucial to future restoration attempts. Although obtaining such information would involve genetic studies, one product of our work will be a set of techniques to enable sex ratio and genetic variation to be assessed relatively easily.

For a variety of reasons outplanting seeds/seedlings is likely to be more successful in the subtidal zone than the intertidal. The intertidal zone is less accessible for restoration efforts than the subtidal because access to the very low intertidal zones where *Phyllospadix* lives is gained only at very low tide and work is limited to a few hours per month. Further, the intertidal may be more stressful for plants and it might be harder for them to establish due to desiccation, thermal or wave stress, or disturbance by people. One possible strategy would be to restore only subtidal zones by outplanting, and let the bed grow upward into the intertidal zone as it matures. It is likely that no matter where restoration efforts take place it will be necessary to protect young seedlings from predation. Complete recovery (even with successful restoration) of a bed could take on the order of a decade or more, rather than months or a couple of years.

APPENDIX II: STUDIES ON GERMINATION AND ROOT DEVELOPMENT IN THE SURFGRASS *PHYLLOSPADIX TORREYI*: IMPLICATIONS FOR HABITAT RESTORATION

APPENDIX III: ALGAL MORPHOLOGY, FLOW, AND SPATIALLY VARIABLE RECRUITMENT OF SURFGRASS, *PHYLLOSPADIX TORREYI*

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.