Seagrass Literature Review and Annotated Bibliography

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Background

CSA Ocean Sciences Inc. (CSA) was contracted by the National Marine Fisheries Service (NMFS) to conduct a literature review and develop an annotated bibliography of information with an emphasis peer-reviewed documents that focused on seagrass restoration, transplantation, mitigation, and recovery. In 1998, Fonseca et al. (1998) compiled a comprehensive annotated bibliography of seagrass information spanning all relevant literature until that time. This document focuses on new papers and findings that span the 16 years from 1998 – 2014. Emphasis was placed on peer-reviewed literature because those meet the Daubert criteria for admissibility in litigation challenges (*Daubert v. Merrell Dow Pharmaceuticals, Inc.*). Documents that contained a seagrass genera currently understood to be native to the United States or its territories were the main focus of this literature review (i.e., *Enhalus*, *Halodule, Halophila, Phyllospadix, Ruppia, Syringodium, Thalassia, and Zostera*).

Information found in this literature review was organized into categories that closely followed that of Fonseca et al. (1998). Information was divided into two general categories: seagrass restoration and seagrass recovery. Documents that discussed seagrass restoration included planting seagrass for restoration or mitigation purposes, transplantation experiments, and planting techniques. Accordingly, documents that discussed seagrass recovery included those that assessed recovery after restoration or natural disturbances. In the literature examined, we found that seagrass recovery was either observed after restoration or natural disturbances, or that experiments were conducted to determine the effects of disturbances on recovery of seagrass. These documents provide information for future seagrass restoration projects and offer vital information on the potential recovery of seagrass to disturbances.

Methods for Seagrass Annotated Bibliography

The literature search for relevant publications was run in the Proquest Dialog databank. The following databases were searched:

- AGRICOLA;
- Aquatic Sciences & Fisheries Abstracts;
- Biosis Previews;
- COS Conference Papers Index;
- National Technical Information Service;
- Oceanic Abstracts;
- PASCAL;
- Proquest Dissertations and Theses Professional; and
- Scisearch.

These databases were searched for the intersection of two sets of bundled search terms, which are identified in **Table 1**. The first set was used to extract information on seagrasses, with particular attention to genera known to occur in U.S. waters and especially those of the southeastern United States. The second set used key words designed to capture topics relating to restoration. The intersection of the two sets produced the working database of seagrass documents related to restoration. Additionally, the same basic search terms were used for Google and Bing Internet searches and for searching OCLC Worldcat, the world's largest and most comprehensive catalog of the library resources from 72,000 libraries around the world, with more than 336 million bibliographic records.

Table 1. The intersection of the following two sets of search terms provided the working database of literature that was further evaluated in the Annotated Bibliography.

Set 1	Set 2
Seagrass* OR "sea grass*" OR Halophila OR Thalassia OR Ruppia OR Phyllospadix OR Syringodium OR Zostera OR Eelgrass* OR Turtlegrass* OR Shoalgrass* OR Manateegrass* OR (eel or manatee or shoal or turtle) n/1 grass* OR Submerg* n/2 vegetation OR SAV OR Halodule OR Enhalus	Restor* OR Recover* OR Plant* OR Transplant* OR Monitor* OR Mitigat* OR Propagat* OR Expansion OR Revegetat* OR Growth OR Mapping OR Distribution OR Recoloniz* OR "die off" OR Dieback OR Declin* OR "Primary production" OR Photosynthe* OR Abundan* OR Relocat* OR Seed* OR Disease? OR Surviv? OR injur* or genetic* OR burial OR nutrient? OR light OR temperature OR salinity OR cost OR fauna? OR bioturbation

" " indicates words are to be searched as a phrase; "*" indicates indefinite truncation of a word; "?" indicates single letter truncation; n/# indicates that the terms should be searched within a certain number of words of one another.

Search Results (1998-2014)

When search efforts concluded at the end of 2014, a total of 2,037 seagrass-related documents was found and placed in a project folder within RefWorks, a web-based bibliographic management software. Prior to full review, additional subfolders were created to separate these documents into six major Topical Areas (TAs); these TAs were selected to provide a thematic breakout of information that has historically had bearing on the planning, execution, and evaluation of seagrass restoration and mitigation projects. The TAs are shown in **Table 2**.

Table 2. Topical Area (TA) documents were organized based on relevant words or phrases in the title (examples given in parentheses).

Topical Area (TA)
1. Factors influencing growth (growth, light, nutrients, salinity, and temperature)
2. Fauna (the effects of faunal species on seagrass)
3. Genetics (documents about the genetics of seagrass)
4. Mapping and distribution (mapping, abundance, and distribution were keywords)
5. Transplantation, restoration, mitigation, and recovery (as stated)
6. Other (if none of the above subfolders fit the document)

Documents that fell into TA #5 (transplantation, restoration, mitigation, and recovery) were those that were set aside to be included in the Annotated Bibliography. These documents were further screened and placed into one of two subcategories for annotation:

1. Work conducted in the United States; and
2. Work conducted in foreign countries, but including only seagrass species found in U.S. waters.

Not all documents were included in the annotation. Those documents can be found in two additional subcategories that were created for reporting:

1. Work conducted in foreign countries and including seagrass species <u>not</u> found in U.S. waters. Those documents were then separated into two subfolders based on the country the study was conducted in: Domestic (United States and its territories) and International (by country); and
2. Abstracts only as in conference proceedings (i.e., not peer reviewed, but topically relevant and for which there was no accompanying formal document). Although this information was recorded, it was seen as having mostly heuristic value because all this work was not peer reviewed while only a limited number of non-peer reviewed but full documents were included in the annotation.

Using this selection process, a total of 366 documents was placed in the Transplantation and Restoration folder (TA #5; **Table 2**). A total of 127 documents was listed in the Domestic subfolder (within the Transplantation and Restoration folder) and were the primary focus of this project. A total of 107 documents was listed in the International subfolder, which was divided into an additional subfolder titled "US Seagrass Genus." This subfolder was created for international documents which studied a seagrass genera that was native to the United States; the remaining documents (foreign and non-US genera) are provided as citations only.

A Microsoft Access (2013 version) database was created based on categories chosen (**Table 3**) to emulate those developed in the previous Guidelines document (Fonseca et al., 1998). This would enable the previous data inventory to eventually be unified with data currently being added.

A detailed list of every option for each category in Access used to describe each document is provided in **Table 4**.

Table 3. List of categories filled in for each document and definitions of each. Where appropriate, study attributes are expanded as shown in **Table 4**.

Categories	Definition
Ref ID	Refworks-generated identification number
First Author	First listed author of the document
Pub Year	Year document was published
Title	Title of document
Keywords	Specific words to describe a document
Country	The country where the study was conducted
State	The U.S. state in which the study was conducted (if not conducted in the United States, this column was left blank)
Latitude (decimal degrees)	Latitude of study area
Longitude (decimal degrees)	Longitude of study area
Literature type	Category of publication (**Table 4**)
Study purpose	Purpose of the study (**Table 4**)
Study type 1	See **Table 4**
Study type 2	See **Table 4**
Species	Species of seagrass studied (**Table 4**)
Area planted	Area of seagrass planted in square meters
Number of planting units	Number of individual planting units planted
Planting method	Method used to plant seagrass (**Table 4**)
Experimental parameters	General methods and treatments used in the study (**Table 4**)
Experimental parameters text	Text to describe experimental parameters in detail
Monitoring parameters	Specific parameters that were monitored during the study (**Table 4**)
Annotation	Three to four sentences describing the results and conclusions of the study

It was determined that the abstract of most documents provided the majority of information needed to fill in each category. However, some abstracts did not provide enough information in several of the documents; therefore, the full document was requested. The abstract, methods, and conclusions sections of the full documents were used to determine which options were the most fitting for each category. Drop-down menus were created for the options and were checked if the option was mentioned in the document. More than one option was usually checked under each category to accurately describe the document. A total of 202 documents, comprising both United States and International documents, was reviewed and entered into the Microsoft Access database.

Table 4. Categories with their associated list of options used to catalog each document in the literature review. To classify a document, selections were made from one or more of the items in each of the following 12 categories. (Species in bold are currently believed to occur in U.S. waters.)

Literature Type	Study Purpose	Study Type 1	Study Type 2
Abstract Book Conference proceedings Primary Technical report Theses/Dissertation	• Economic analysis • Guideline • Methods development • Mitigation • Monitoring • Recovery • Research • Restoration	• Field • Laboratory • Review/Case Study	• Cost analysis • Experimental • Mesocosm • Microcosm • Modeling • Observational

Species	Planting Method	Experimental Parameters	Monitoring Parameters	
Amphibolis antarctica *Amphibolis griffithifif* *Cymodocea nodosa* *Cymodocea rotundata* *Cymodocea serrulata* ***Enhalus acoroides*** *Halodule beaudettei* *Halodule pinifolia* *Halodule uninervis* ***Halodule wrightii*** *Halophila australis* *Halophila beccarii* ***Halophila decipiens*** ***Halophila engelmannii*** ***Halophila hawaiiana*** ***Halophila johnsonii*** *Halophila minor* *Halophila nipponica* *Halophila ovalis* *Halophila spinulosa* *Halophila stipulacea*	• Bare root • Buoy seed dispersal • Epoxy • Grid/TERF • Hand broadcast • Hand planting • Mechanical boat • Mesh • Nylon net • Peat pot • Peat pellet • Pipet • Plug • Rope • Rubber band • Skewers • Staple • Surface dispersal • Turf	• Algae • Bioturbation • Bird stakes • Burial recovery • Cost analysis • Donor survey • Enclosure • Excavation • Fatty acid • Fauna • Fertilization • Filled sediment • Genetics • Herbivory assays • Lab cultivated • Large planting units • Light • Light intensities • Mapping • Method	• Aerial coverage • Algae percent cover • Biomass (above/below) • Buoy position • Canopy height • Carbon • Chlorophyll *a* • Chlorophyll content • Current • Digitization • Dry weight of growths • Dry weight of roots • Fauna densities • Faunal colonization • Faunal counts • Floral density • Epiphytes • Excavation depth • Heterozygote frequency • Hexp value	• Roving fish count survey • Salinity • Scar width • Seagrass percent cover • Sediment organic matter • Sediment particle size • Seed counts • Seedling counts • Seedling density • Sheath length • Shoot counts • Shoot density • Shoot height • Shoots per genet • Shoot to root ratio • Species • Stem length • Suspended solids/turbidity • Temperature

Table 4. (Continued).

Species	Planting Method	Experimental Parameters	Monitoring Parameters	
Heterozostera tasmanica *Phyllospadix japonicus* ***Phyllospadix scouleri*** ***Phyllospadix serrulatus*** ***Phyllospadix torreyi*** *Posidonia angustifolia* *Posidonia australis* *Posidonia coriacea* *Posidonia oceanica* *Posidonia sinuosa* ***Ruppia maritima*** ***Syringodium filiforme*** *Syringodium isoetifolium* *Thalassia hemprichii* ***Thalassia testudinum*** *Thalassodendron ciliatum* ***Zostera asiatica*** *Zostera capricorni* *Zostera caulescens* ***Zostera japonica*** ***Zostera marina*** *Zostera muelleri* *Zostera noltii* *Zostera pacifica* *Zostera tasmanica* Other Unspecified	• Other • Unknown	• Model • Monitoring • Nitrogen fixation • Nutrient injection • Planting • Planting unit spacing • Pre or pre vs post • Protected vs unprotected • Recovery • Redox • Season • Sediment • Sediment bacteria • Sediment cores • Seed dispersal • Seed harvesting • Seed storage • Sexual reproduction • Shading • Shoot harvesting • Stable isotope • Success criteria • Sulfide • Tidal zone • Transplanting techniques • Water flow • Water quality	• Hobs value • Image classification • Inbreeding frequency • Leaf growth rates • Leaf length • Leaf nutrients • Leaf width • Leaves per shoot • Light • Nitrogen • Oxygen • PAM fluorometer • PAR • Patch expansion • Patch size/perimeter • Percent survival • pH • Phosphorus • Photographs • Plant productivity • Plant unit density • Porewater sulfide • Rhizome diameter • Rhizome elongation rate • Rhizome internode length • Rhizome length • Root counts	• Video • Water depth • Wet weight

PAM = pulse amplitude modulation; PAR = photosynthetically active radiation; TERF = transplanting eelgrass remotely with frames.

Results and General Findings

DOCUMENTS STATISTICS

Using the online search engines, the most frequently encountered document type was the primary or peer-reviewed journal publication literature (**Figure 1**). Because the annotated bibliography will be used to guide agency policy, reliance on peer-reviewed literature was appropriate.

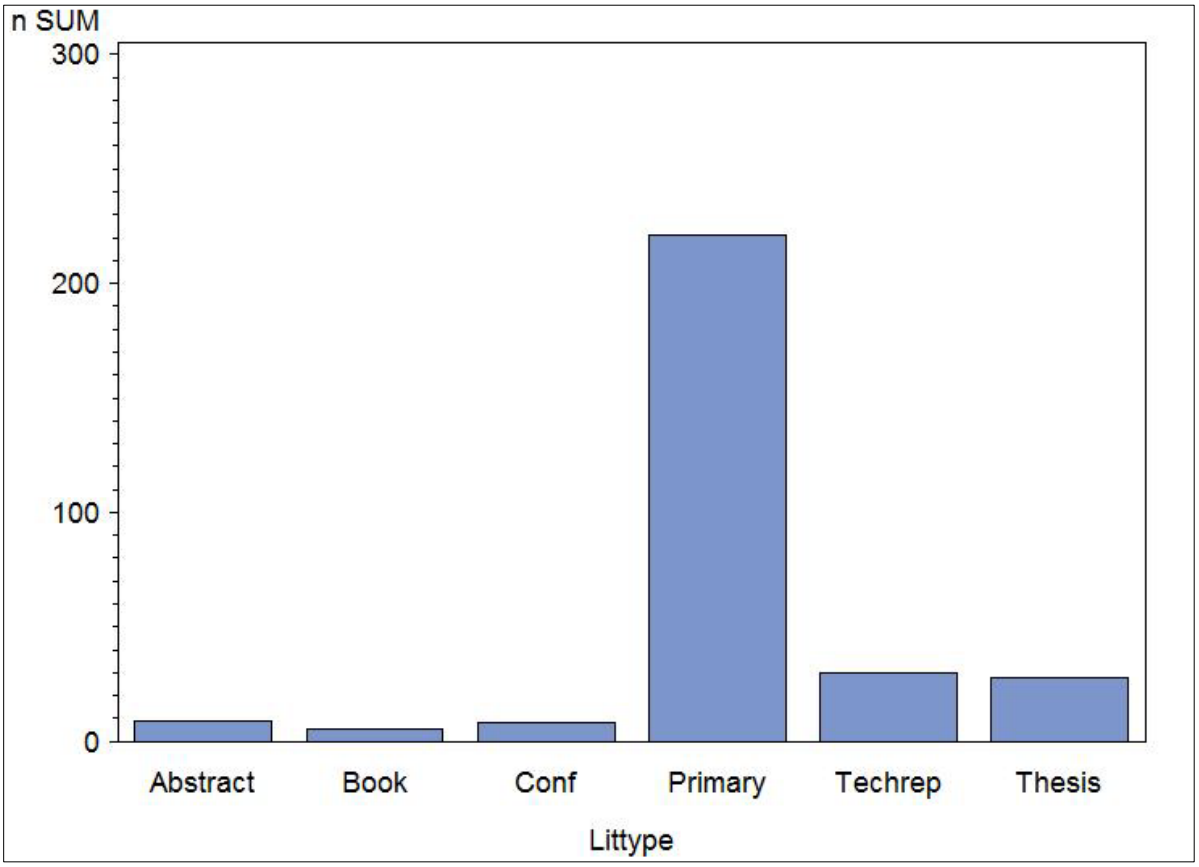

Figure 1. Sum of documents by literature type.

Figure 2 reveals that most of the published work on seagrass restoration has been from the United States. Australia (9%), Korea (7%), and Japan (6%) were other countries from which documents frequently encountered. European documents accounted for approximately 11% of the total.

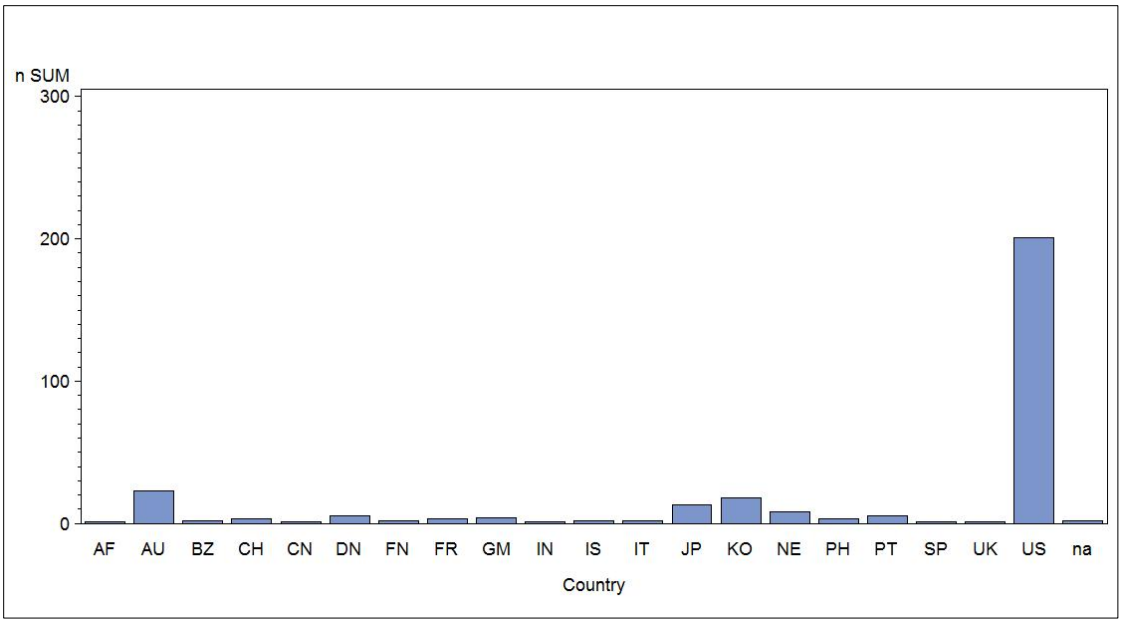

Figure 2. Sum of documents by country or region. AF = Africa; AU = Australia; BZ = Brazil; CH = China; CN = Canada; DN = Denmark; FN = Finland; FR = France; GM = Germany; IN = India; IS = Israel; IT = Italy; JP = Japan; KO = South Korea; NE = The Netherlands; PH = Philippines; PT = Portugal; SP = Spain; UK = United Kingdom; US = United States; na = review or theoretical topics with no specific country.

Among those documents originating from the United States, most work had occurred in Florida (**Figure 3**). Virginia and Maryland had the next highest numbers and may be viewed as a continuum of work, almost exclusively on eelgrass, *Zostera marina*. The category "na" (**Figure 3**) refers to studies either among multiple states or were of a theoretical nature.

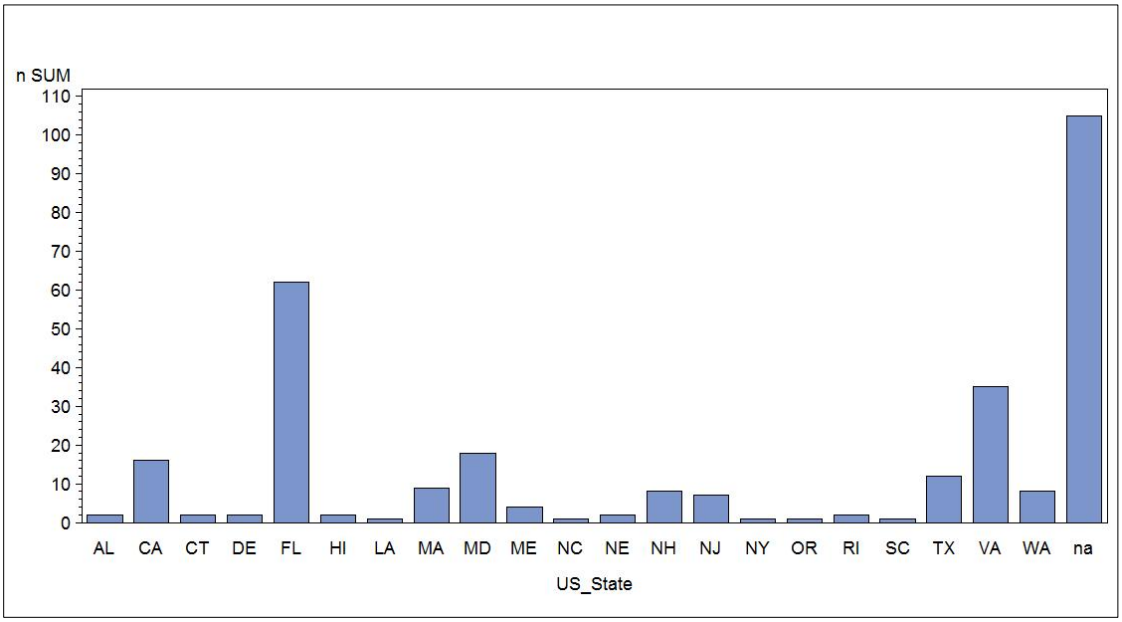

Figure 3. Sum of domestic documents by state.

Figure 4 shows the publication numbers by years involved in the annotated bibliography. No apparent pattern of publication frequency was discernible; the average was approximately18 documents per year.

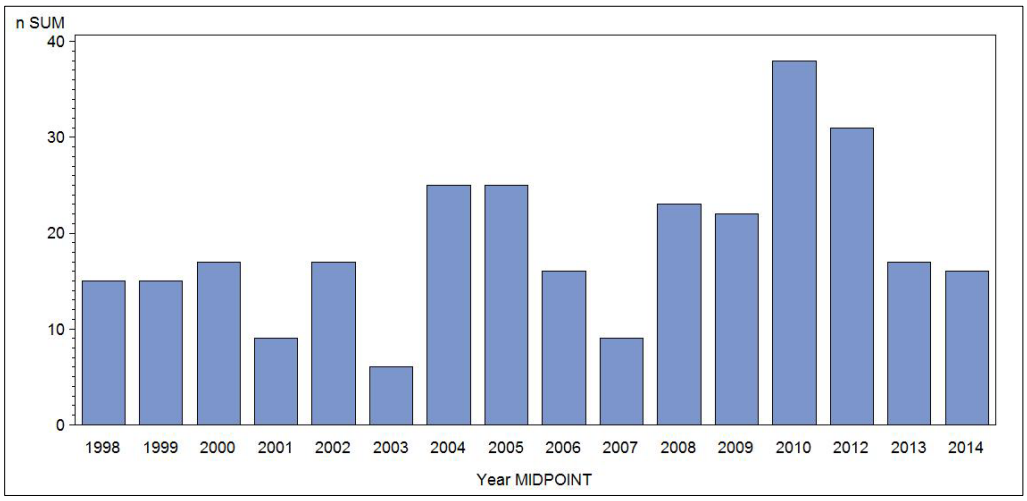

Figure 4. Sum of documents by year.

SYNTHESIS OF FINDINGS

Seagrass recovery was specifically studied in 51 documents in this literature search. Overall, recovery times depended on the severity of the disturbance to the seagrass bed; longer recovery periods were associated with larger and more severe injuries. The mode of recovery depended on the seagrass species, either through sexual or asexual reproduction. Species that did not produce large amounts of seeds or species with fast rhizome elongation rates, primarily recovered using asexual propagation from adjacent seagrass beds. Other species that produced seeds with a wide distribution range or species with a perpetual seed bank, recovered mainly by sexual reproduction. Recovery periods depended on the species, environmental conditions, the severity and duration of the disturbance, bioturbation from fauna, and the proximity of adjacent seagrass meadows available to aid in recovery.

Seagrass restoration was the focus of 118 documents and emphasized restoration site selection, donor site selection, planting, and transplantation techniques. Appropriate restoration site selection was repeatedly mentioned as necessary for increasing the success of restoration projects. The use of models, augmented by GIS maps and historical records of site conditions, were occasionally used in attempts to predict restoration success otherwise site selection tended to be guided by best professional judgement. Environmental conditions of the site such as weather, water quality, water depth, light availability, tidal flow, water dynamics, temperature, salinity, and substrate type were all factors considered in the assessment process. The use of test plantings were only occasionally used to evaluate the planting conditions mentioned.

Donor site selection was also mentioned as an important step for restoration. It was recommended that the donor site should have as many characteristics similar to the restoration site as possible to avoid unnecessary stress on the transplants. In addition, donor material should be selected according to what was previously reported for the restoration site and nearby areas. Donor sites with larger seagrass populations were considered to have a higher genetic diversity, which was expected to increased population growth and viability. Thus, increased genetic diversity from donor sites was seen as beneficial for seagrass restoration.

More than 25 different seagrass planting techniques were discussed throughout these documents. Selection of the appropriate technique largely depended on the targeted species and the restoration site. Planting techniques for seedlings or adult seagrass mentioned in these documents included staple, peat pot, plug, turf, shell, oyster shell, stone anchor, bamboo skewer, grid (transplanting eelgrass remotely with frames [TERFs]), bare root, sod, mat, rope, hand planting, and mechanical planting. Use of seeds for restoration projects was suggested for only one seagrass species (*Z. marina*). The benefits were twofold: 1) it was more cost effective than harvesting and planting seedlings or adult plants, and 2) an increased range of genetic diversity was observed at the restored site. Planting techniques for seeds included hand broadcasting, mechanical surface dispersal, mechanical planting, pipet, seed tape, and buoy dispersal. Seasonality was mentioned as an important factor to consider for restoration success. Planting in the late autumn and winter was recommended over planting in the summer for most temperate seagrass species.

Effects of fertilizer were examined in seagrass restoration and recovery with varying effects on seagrass growth, and mainly depending on the species. In some species, fertilization enhanced initial propagation but it had no effect on survival, and in other species fertilization had no effect on seagrass. In general, fertilization effects were minimal except for projects conducted in carbonate sediments on *Halodule wrightii*.

Fauna were observed to have varying effects on seagrass restoration and recovery. Lugworm (*Arenicola marina*) populations negatively affected seagrass recovery by burying seeds and seedlings. Green crabs (*Carcinus maenas*), clam worms (*Neanthes virens*), and other marine worms (*Nereis* spp.) negatively affected seagrass transplants via bioturbation of the substrate. Despite the generally acknowledged effects of stingrays on restoration success, few documents dealt with this issue.

PROJECT DELIVERABLES

Project deliverables are in accordance with Task Order requirements. The annotated bibliography is provided along with the supporting original references in a Word 2010 file on a CD/DVD. CSA is allowed to provide the original reference documents *in toto* to a government agency; however, the agency is cautioned against republishing those documents in any manner not consistent with fair use expectations of the publishers. In addition, CSA is providing a Word document listing the references not annotated; these were the references of work conducted outside the United States and on seagrass genera not known to occur in U.S. waters. Although not specified as a deliverable an electronic copy of the annotated bibliography is provided in Excel format.

References

Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Guidelines for the conservation and restoration of seagrass in the United States and adjacent waters. NOAA COP/Decision Analysis Series. 222 pp.

Daubert v. Merrell Dow Pharmaceuticals, Inc. 509 U.S. 579, 584-587 (1993). Website accessed 26 May 2015 at: https://scholar.google.com/scholar_case?case=827109112258472814&q=Daubert+v.+Merrell+Dow+Pharms.,+Inc.,+509+U.S.+579,+584-587&hl=en&as_sdt=40003.