Eelgrass Restoration Handbook:

the how, when and where of restoring eelgrass habitat

Funded by The Anthropocene Institute

Kathryn M. Beheshti, UC Santa Cruz

Brent B. Hughes, UC Santa Cruz

Kathy Boyer, San Francisco State

Susan Williams, UC Davis

Table of contents

INTRODUCTION

The purpose of this handbook is to serve as a resource to managers and researchers leading seagrass restoration and/or mitigation projects. The content of this handbook is based on a seagrass (Zostera marina) restoration project carried out in Elkhorn Slough, an estuary located in Monterey Bay, California.

The restoration in Elkhorn Slough was successful with ~40% of plots remaining two years post-transplanting and restoration area reaching up to 215 times the original plot size.

Recently there has been a call to begin incorporating feedbacks into the framework of restoration and conservation management of coastal systems (Maxwell et al., 2017; Nyström et al., 2012; Suding, Gross, & Houseman, 2004). In terrestrial systems restoration ecologists have been integrating feedbacks into the management of degraded systems for some time (Mayor et al., 2013; Suding et al., 2004). Yet, research focused on the interaction of feedbacks at various spatial scales is in its infancy as it relates to the practical application of restoration and ecosystem management. Seagrasses are model systems for exploring such interactions in a restoration context.

Seagrasses are classified as foundation species due to both their ability to directly modify the physical environment in which they inhabit and through their catalytic role as trigger to a suit of ecosystem processes and feedbacks (Maxwell et al., 2017; Van Der Heide et al., 2007). Such feedbacks include self-reinforcing positive feedbacks. For instance, the three-dimensional structure of eelgrasses attenuates the flow of sediment-laden water which allows particulates to drop out and eventually become buried or sequestered. The seagrass ecosystem function of sediment trapping improves local water clarity which enhances the photosynthetic capacity and depth range of seagrasses.

The majority (63%) of seagrass restoration attempts to date have been classified as unsuccessful (van Katwijk et al., 2016). Meta-analyses on global seagrass restoration efforts have emphasized the importance of site selection, scale of restoration and the reversal of degraded or undesirable environmental conditions for re-establishment, while maintaining that such generalities do not supersede local, system-specific expertise which should ultimately inform restoration design (van Katwijk et al., 2016). Building on the knowledge gained from previous local restoration work led by our team of researchers, we have developed this “how to” handbook to aid managers in successfully carrying out a seagrass restoration and/or mitigation project.

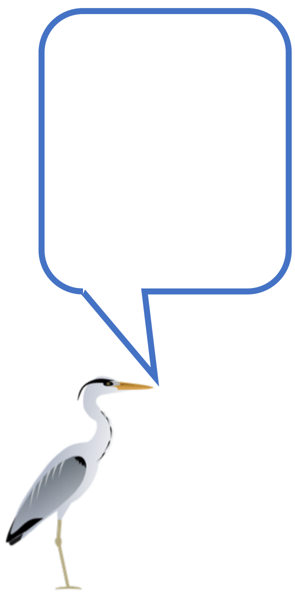
Happy planting,

Kathryn Beheshti, Brent Hughes, Kathy Boyer & Susan Williams

NAVIGATING THE HANDBOOK

This handbook is structured as a resource for managers and practitioners interested in eelgrass restoration. The table of contents provides the general outline, but there are a few things to look out as you continue reading.

1



When you see this Great Blue Heron commenting on a page, take note! These will be relevant comments or suggestions provided by one of our research team members.

2

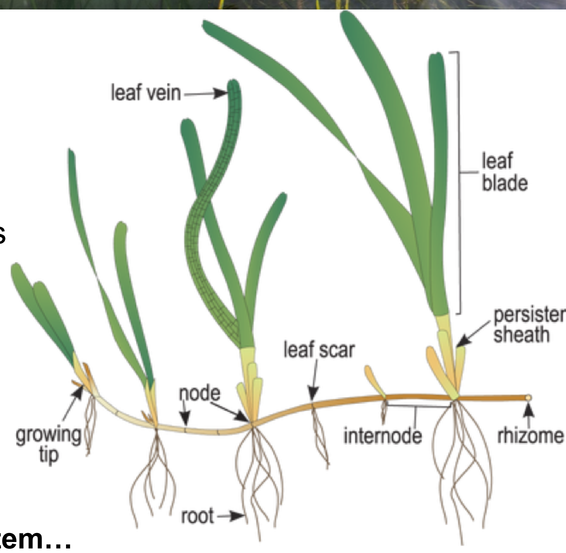
* If you see an asterisk next to any word throughout the handbook, a **definition** can be found in the Glossary on page X.

3

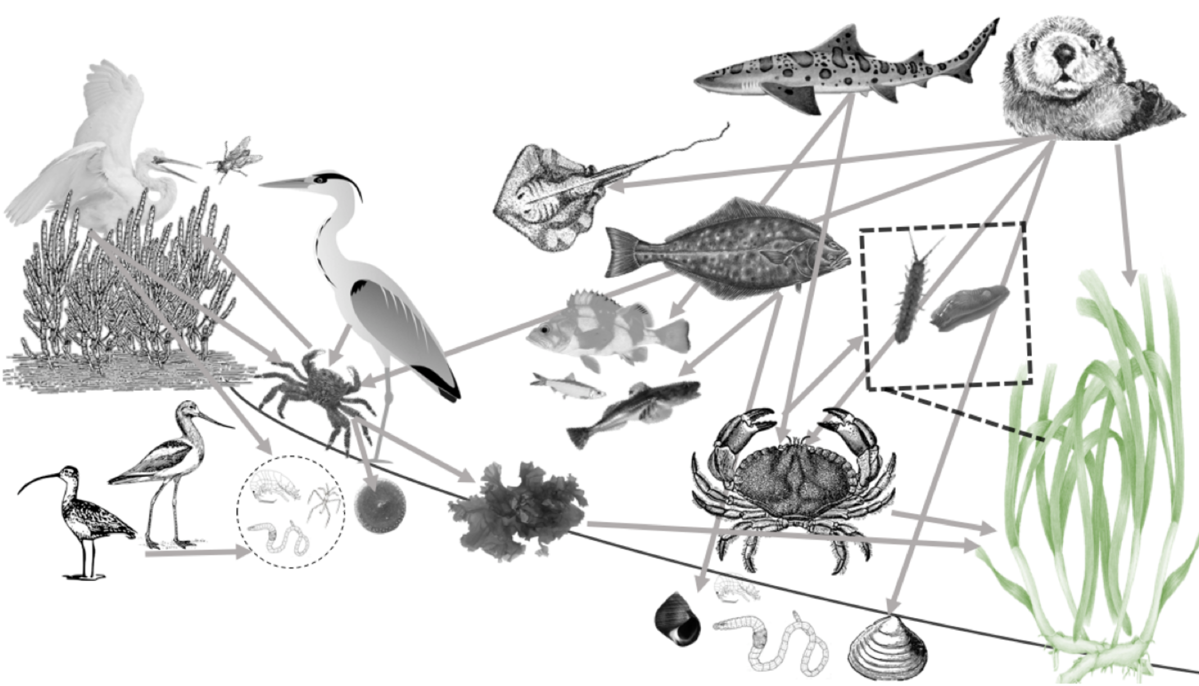
An italicized note at the bottom of the page will direct you to where you can find more information/resources relevant to that chapter/subject

QUICK INTRODUCTION TO THE TARGET SPECIES: EELGRASS (*Zostera marina*)

- Scientific name: *Zostera marina*
- Common name: Eelgrass
- Family: Zosteraceae
- IUCN status: Least Concern (iucnredlist.org), yet population trend is decreasing
- Like all seagrasses, *Zostera marina*
- is an aquatic angiosperm*



Eelgrass is part of a complex coastal system…



ASSESSING LOCATION SUITABILITY

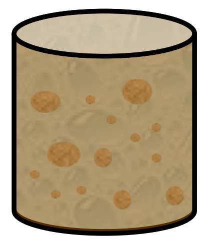
Favorable conditions conducive to enhancing restoration success include but are not limited to site characteristics listed below. A well-flushed system with moderate nutrient levels is ideal.

GOOD SITE CHARACTERISTICS

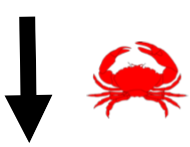
POOR SITE CHARACTERISTICS

Degree of light attenuation* (function of turbidity and depth)

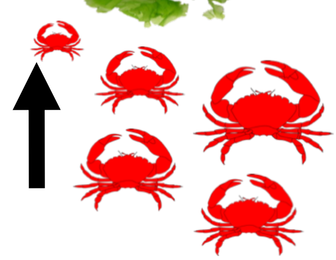
Turbidity* (function of water velocity, sediment type and benthic invertebrate community)

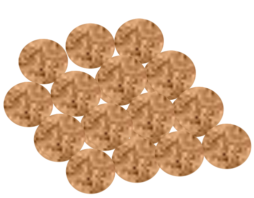


Algal growth (function of nutrients, season, space availability (i.e. competition))

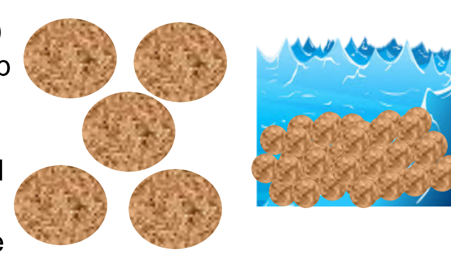


Crab density (function of food availability (grazer abundance), predation pressure, top down control). Hughes et al., 2013





Sediment that is too coarse (right) will a) be difficult to transplant deep into substrate and/or b) seagrass will easily become dislodged. Sediment that is too fine/saturated (right) a) cause transplant to sink into the mud and/or b) will lack the stability needed for the shoot to take root.



ASSESSING LOCATION SUITABILITY

THE SYSTEM:
An ideal system for eelgrass restoration would meet the following criteria:

- Well-flushed system, strong outgoing and incoming tides.
- High current speed has the potential to rip out transplanted shoots. Consider maximum water velocity during spring tidal cycles before transplanting. *Depth limits can pertain to both light limitations and current speed. It is likely that most restorations following our technique will be in the 0-2m MLW and thus, current speed may not be a relevant concern.*

What you want=moderate nutrient levels

Oligotrophic* (nutrient poor) **Eutrophic* (nutrient loaded)**

Things to consider…

- More nutrients = ↑ algae = ↑ competition with transplanted eelgrass = increased risk of restored plot mortality

If possible, deploy water quality instrument(s) (i.e. YSI sonde) to directly measure turbidity at the proposed restoration site.

Dr. Brent Hughes (pictured left) showing how prolific algal production can be in a eutrophic system. Ephemeral* macroalgal blooms can contribute to restoration plot mortality by outcompeting transplanted plots for space, light and other resources. Transplanted plots can become smothered by ephemeral macroalgal mats like the one pictured here.

- Low turbidity
  - Sandy sediment is better (typically less turbid)
  - Silty sediment will be easier to transplant in, but will have poor water clarity
  - Candidate sites with light levels fall below 3 μmol/m^2 /s should be ruled out as they do not meet the minimum light requirement for *Z. marina*. (Thom et al. 2008)

See "Further Resources" page for further advising on site-specific water quality data.

ASSEMBLING RESEARCH TEAM

Depending on the goals of the restoration project, some can require a large team. Logistically, this can be difficult depending on where and when the restoration is planned. It is best to assemble your team far in advance of the actual transplanting to ensure that you have the required help. For example, if you and your team plan to transplant in Winter by foot you may be limited in possible field days by weather, the shorter hours of daylight and ideal low tides tides. Knowing how large of a field crew you need and scheduling out in advance all possible field days will allow you the flexibility to cancel due to poor conditions.

WHO YOU WILL NEED TO CARRY OUT A SUCCESSFUL RESTORATION PROJECT

DIVE TEAM: *For more information see page 4.*

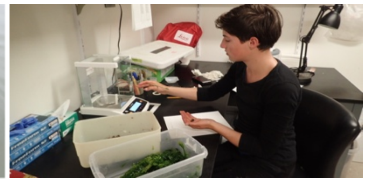
UNDERGRADUATE RESEARCH TEAM: *For more information see page 4.*

PROJECT LEAD: *For more information see page 4.*

DATA MANAGEMENT: *For more information see page 4.*

If you are associated with a university and you plan to conduct your restoration using SCUBA, you must make sure that all divers participating are AAUS Certified*.

ASSEMBLING RESEARCH TEAM



WHO YOU WILL NEED TO CARRY OUT A SUCCESSFUL RESTORATION PROJECT

DIVE TEAM: SUBTIDAL RESEARCH EXPERIENCE NEEDED. We suggest having a large team of available and current divers. It is often the case that dive days get moved around because of field conditions. Having a large dive team will allow you to more easily find available divers. Divers must have experience and be comfortable diving in low-visibility conditions and have great buoyancy control.

UNDERGRADUATE RESEARCH TEAM AND/OR CITIZEN SCIENTISTS: During the restoration itself, there is a great deal of work that can be done on the boat as “surface support”. This is a great opportunity for undergraduates/citizen scientists that are not SCUBA certified but would like to be involved. Having a designated surface support person to remain on the boat while divers are down is ideal both for increased efficiency and safety reasons. If no boat is available it is critical that all chosen sites are accessible by land. These team members are also critical for all lab processing related to the restoration.

DATA MANAGEMENT: Training undergraduates/volunteers and interns on how to properly enter data and QA & QC the data will save time and allow undergraduates/volunteers to sharpen their skills of data entry, data analysis and identifying how to structure datasheets for the field so that they fall into the format of the data entry spreadsheet.

PROJECT LEAD: A project lead is necessary for a) planning the logistics of the field work, b) coordinating the schedules of the research team, c) making sure that all necessary supplies are gathered by the undergraduate research team prior to any field days, d) to supervise, train and instruct the research team, e) to ensure all permits, waivers and miscellaneous forms are on-hand while in the field, f) to troubleshoot any issues in the field/lab and g) to be lead author on any publications that result from the restoration and to analyze all data collected.

See Page 9-10. for examples of field datasheets

FIELD DATASHEET EXAMPLE

Field datasheets will likely be structured in a condensed version of how data will be entered. This is done to economize on datasheet space and more efficiently collect data in the field by avoiding entering data in multiple unneccessary columns.

PROJECT TITLE: ELKHORN SLOUGH RESTORATION 2016

Name(s):___________________
Date:______________________
Site:______________________

METADATA
Hight Tide(HT):______ Low Tide (LT):_______
HT_Time:__________ LT_Time:__________
Weather Conditions:_______________________________

PLOT_ID	#_SHOOTS	#_FLOWERING SHOOTS	%_COVER_ ALGAE	PLOT_AREA (cm)	CANOPY _HEIGHT (MAX)	NOTES
Ex. A_1_R16	25	6	5	257x455	103	algae accumulated on PVC post marking plot area

FIELD NOTES: Plot_ID written as STRATA_PLOT#_RESTORATIONYEAR---> A_1_R16 reads Strata A, Plot #1, Restoration 2016
Saw juvenile rockfish in B_2_R16, large Aplysia californica in A_8_R16 and C_7_R16

We suggest printing all field datasheets on underwater paper (UW). If printing on UW paper, make sure (TEST!) that the printer you use has this ability.

See page 10 for an example of how data should be entered after the field day

DATA MANAGEMENT EXAMPLE

Data management is often led by the project lead or P.I. All data must be double checked (QA & QC'd) for entry errors by at least two people following initial data entry. Metadata should be entered in a separate sheet within the same excel workbook. Including metadata in your main data entry sheet can make data analysis more difficult later on.

METADATA

Field Date:______
Data Entry Date:_________
Name(s) of field crew:________________________________
Name(s) of data entry personell:_______________________
Excel File Name:____________________________________
Corresponding Excel Sheet Name: ____________________

Hight Tide(HT):______ Low Tide (LT):_______
HT_Time:___________ LT_Time:____________
Weather Conditions:________________________________

Field Notes: ____

Date	Initials	Sheet_Name	Note
1/28/18	KMB	R2016Monitoring_Data_01082018	field data entered up to field day 1/10/2018
1/29/18	KMB	R2016Monitoring_Data_01082018	all data entered, need to QA/QC

date	strata	plot_#	restoration_year	#_shoots	#_floweringshoots	%_cover_algae	plot_area_x_cm	plot_area_y_cm	max_canopy_height	notes
1/1/18	A	1	2016	25	6	5	257	455	103	algae accumulated on PVC post marking plot area

Data should be entered so that it can be analyzed using the preferred statistical software (R, excel, SYSTAT, PRIMER, JMP, etc)

NEEDED SUPPLIES

MUST HAVE SUPPLIES: garden stakes, trowel, mesh bags of some sort, cooler, trowel and sheers/scissors






Budget/supply list will vary.
For example…

- If transplanting is done at low tides and by foot (not SCUBA), then SCUBA tank costs can be removed.
- Boat costs and transportation costs will vary by project site and organization.
- If not interested in quantifying light availability, HOBO equipment can be removed from budget

SAMPLE SUPPLY LIST:

Expense Category	Description
Laboratory	HOBO BASE U-1 Pendant Optic Base Station/Coupler: for calibrating pendants for deployments and offloading data when pendants are retrieved from the field.
Field Work	HOBO Temperature/Light 8K Data Logger: for measuring light and temperature in monitored habitat types
Field Work	Garden staples: for transplanting shoots
Field Work	Hand trowel: for transplanting shoots into ground
Field Work	1" PVC (white, 10'): for marking plot location
Field Work	1" PVC (white 10'): for building quadrats used during transplanting process and subsequent monitoring of plots
Field Work	PVC elbows: for quadrat (1" Schedule 40 PVC 90-degree elbow)
Field Work	Mesh bags; Eco Produce Bag Premium Reusable Mesh Bags, set of 5 draw string with color tags: for harvesting for transplanting & collecting shoots for lab processing
Field Work	UCSC IMS-SCUBA tank fills: for transplanting/harvesting/monitoring restoration plots
Field Work	ESNERR Boat Gas: for access/transportation to field site
Field Work	Total mileage round trip from Long Marine Laboratory to field site (Elkhorn Slough): 60 miles (using personal vehicle)



See Page 19 for information regarding permits

LOGISTICS OF FIELD WORK

WHAT YOU NEED TO CONSIDER

Are you transplanting on SCUBA (high tide) or by foot (low tide)

What is the ideal time for restoration on SCUBA?

Typically…

1. Strong spring tide cycle (well-flushed, open coast water flowing in, typically better visibility during Spring tide)
2. Incoming tide
3. Sunny day (better light penetration/visibility)
4. Calm weather day (low wind, no rain)

What is the ideal time for restoration on foot?

Typically…

1. Low tide of spring tidal cycle
2. Outgoing tide

Generate a list of supplies that need to be gathered and packed the day prior

Typically you will need…

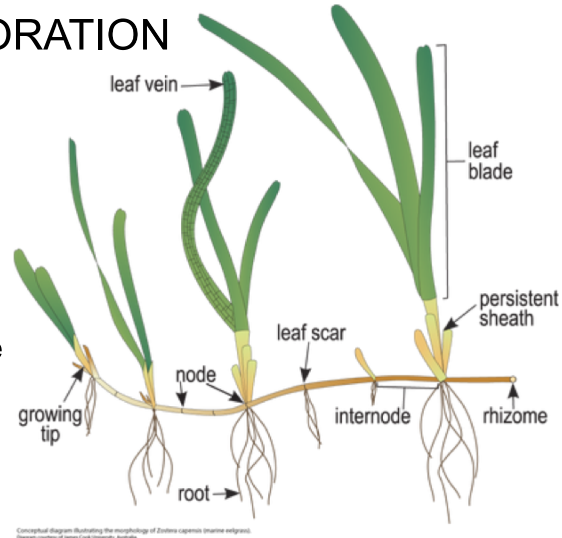
1. Mesh bags
2. Trowel
3. Quadrat
4. Garden staples
5. Transect tape
6. Cooler
7. Scissors
8. SCUBA gear OR waders
9. O2 & AED Kit, First Aid Kit
10. Datasheets on underwater paper
11. PVC for marking plot location
12. GPS

We suggest transplanting on SCUBA when possible. Logistically it is more complicated to transplant on SCUBA (more gear to account for, need AAUS scientific divers or divers subtidal research experience, etc.). But, there is less trampling, you are able to cause less disturbance and you are planting when the plot area is inundated which may enhance restoration success.

HARVESTING FROM DONOR BED

HOW TO HARVEST FOR THE RESTORATION

Harvest from the largest, most dense and resilient bed for the restoration.

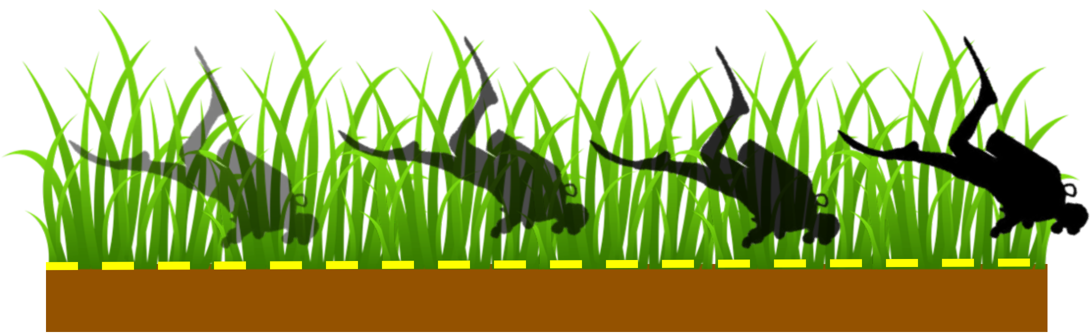


Key points about harvesting…

- Harvest shoots including the growing tip

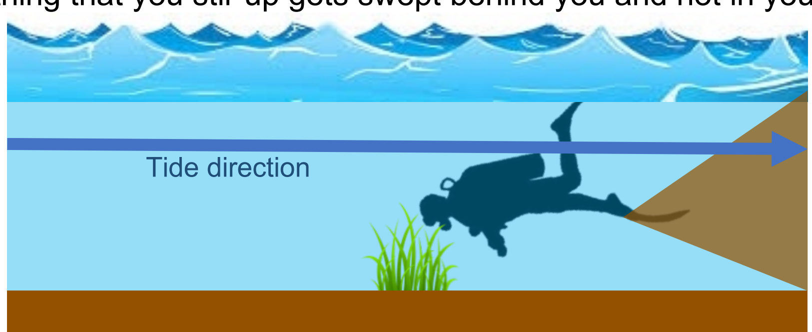
- *Never* harvest all shoots from a single area of the bed. *Always* harvest one shoot, move a meter or so and harvest another shoot and continue across the bed.

- Pull each shoot from the base of the plant and pull firmly and slowly to ensure that the a long, intact rhizome is also collected with the target shoot.

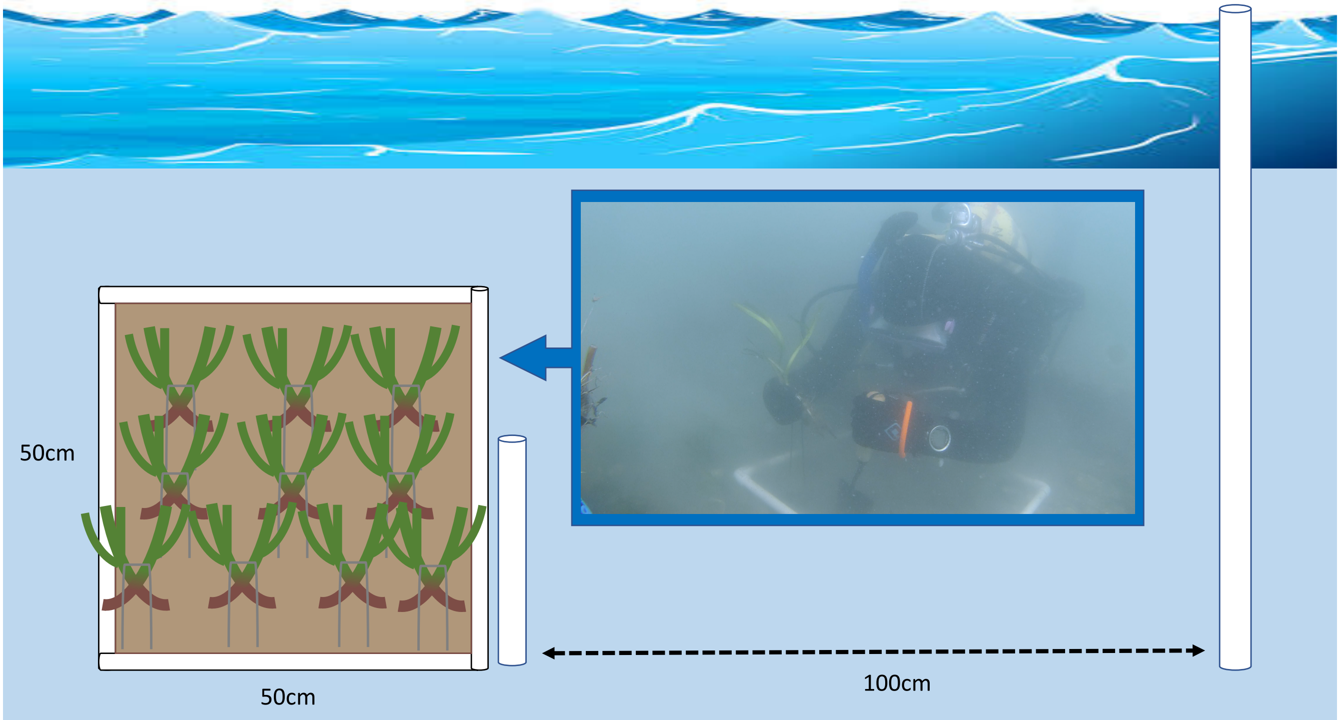


- If harvesting at low tide (*NOT ON SCUBA*) the protocol would be the same, you would harvest randomly and over a very large area to a) harvest a representative sample of the bed, b) avoiding creating bare patches and c) enhance the likelihood of higher genetic diversity of harvested shoots.

- Always have your dive fins kicking in the same direction that the tide is moving in so that anything that you stir up gets swept behind you and not in your transplanting area.



TRANSPLANTING



GENERAL NOTES ON TRANSPLANTING

Can also use bright colored flagging tape to find plots. If transplanting on SCUBA, finding plots can be difficult when visibility is limited

- If possible, place a 5' PVC post ~100cm from the restored plot so that you can find the plot easily for monitoring plots post-transplanting.

- Place a shorter PVC post in the ground in the same position for each plot relative to the quadrat. The quadrat marks the restored plot initial area. Placing the PVC on the onshore-west corner of the plot will allow you to properly identify the original plot area through time.

- For SCUBA: Tie the quadrat to your dive gear. Sediment gets easily resuspended when transplanting and you can lose sight of the quadrat and won't be able to recover it. If you have all your field gear tied to your BCD or wrist using a long line you will decrease the chances of losing field gear.

- For SCUBA: Always have a surface support person and use a dive flag whenever divers are in the water. Having someone on the boat as the designated "dry" person can make navigating to sites using sensitive GPS, recording data NOT on underwater paper, prepping transplanting bundles and sorting through and labeling samples.

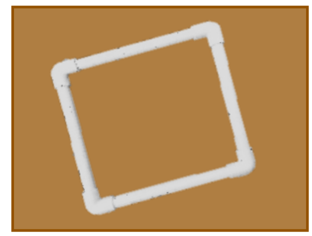
- Planting density: In our Elkhorn restoration we transplanted 20 shoots per 50x50cm plot. Two shoots we positioned in opposite directions with the garden staple securing the rhizome of both transplants. (See above cartoon)

TRANSPLANTING

1. Place harvested shoots in cooler with fresh seawater

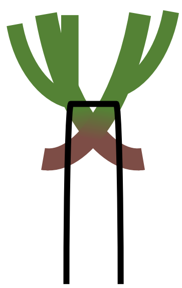
2. Trim shoots and sort into bundles of 20 shoots secured with loose zip ties

3. At restoration plot site drop down quadrat and plot marker (PVC that you will need to mallet into the substrate)

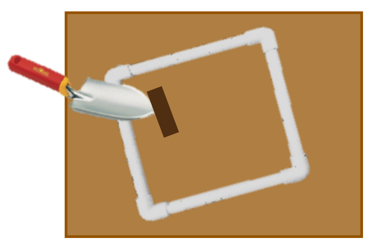


4. With bundle of trimmed shoots, garden staples and trowel, begin transplanting process

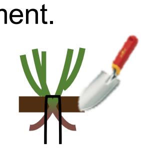
5. Grab 1-2 shoots and a single garden staple



6. Make narrow slit in the sediment within the designated plot area (indicated by quadrat)



7. Carefully place shoots & staple into ground with cut-end of rhizome inserted into slit in sediment with rhizome meristem nearest to the surface with a thin layer of sediment.



Depending on how many garden stakes and how much time you have to transplant each plot, you may want to transplant one shoot per staple. For our restoration logistically we needed to transplant 2 shoots/staple. The density per plot is the same, the organization of the shoots is what differs.

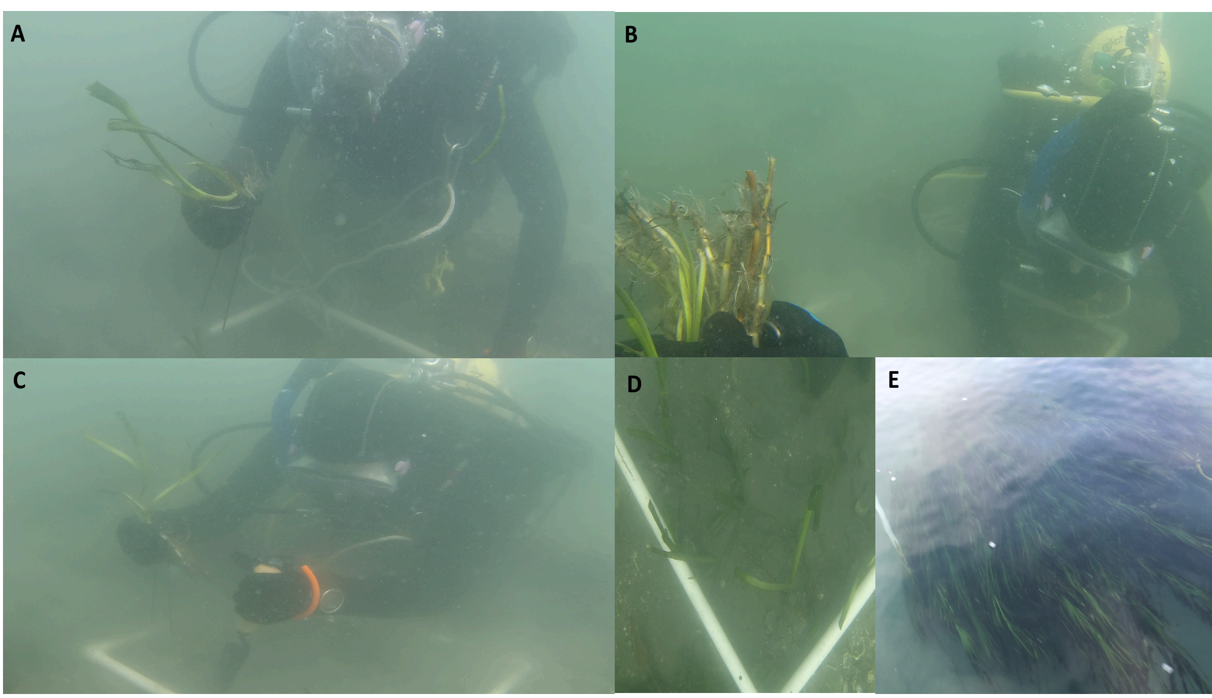
8. Repeat steps 5-7 until you reach the desired plant density in the plot

TRANSPLANTING

EELGRASS RESTORATION PROCESS: SCUBA METHOD

Transplants will do better if shoots include growing tip and healthy, intact rhizome meristem. We also suggest that when transplanting, the cut end of the rhizome be inserted into the sediment slot made by the trowel, leaving the rhizome meristem resting at the the top of the slit.

A) On SCUBA dive buddies descend with trowel, shoots in mesh bag, garden stakes and PVC quadrat
B) Dive buddy hands “transplanting diver” shoots (cut to standardized length of 20cm) and garden stakes
C) “Underwater gardening”; “transplanting diver” uses trowel to transplant the eelgrass shoots into the restored plot area
D) Depicting what the plot looks like immediately after transplanting
E) One year-post transplanting the plots have grown both in terms of canopy height (or shoot length) and plot area (or expansion). This photo was taken at low tide from the surface.



- If harvesting at low tide (NOT ON SCUBA) the transplanting protocol would be the same. A benefit of transplanting on foot at low tide is that you can transplant more plots because you do not have to be in buddy pairs. You could have multiple research team members transplanting individual plots and you would not be limited by who is “qualified” to transplant, as you are when transplanting on SCUBA (must be AAUS Scientific Divers or experienced subtidal research divers).

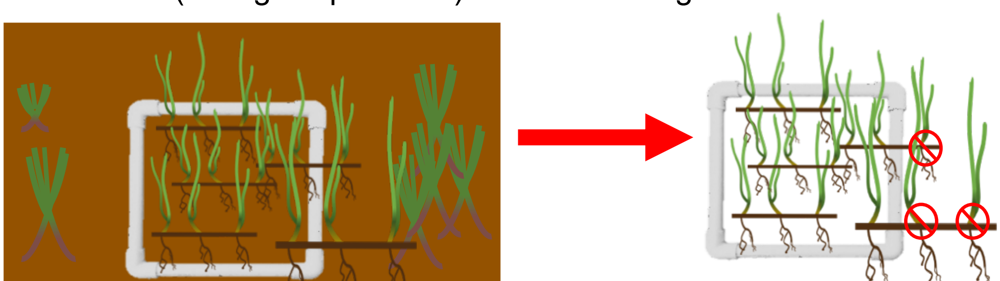
MONITORING

The monitoring protocol of your specific restoration will be site/project specific. Depending on the goals of your restoration and how it will be managed post-transplanting. We encourage practitioners to initiate a long-term (5-year minimum) monitoring program for each restoration.

Monitoring your restoration plots is critical if you are interested in tracking the progress of the restored plots, quantifying the expansion rate of the plots, mortality rate, survivorship, likelihood of survival, new shoot growth, etc. We suggest conducting concentrated monitoring of restored plots in the first two years post-transplanting at months 1,3,6,9 and 12 post-transplanting for year 1 & 2.

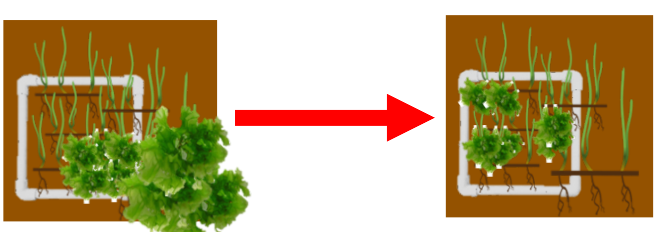
Data collected when monitoring may include the following parameters: Please note that monitoring may have to comply with specific mitigation requirements. In such instances, the below list may be too extensive or not detailed enough.

- Shoot count (in original plot area) & # of flowering shoots



12 shoots within the original plot area

- % cover algae (by eye estimate)



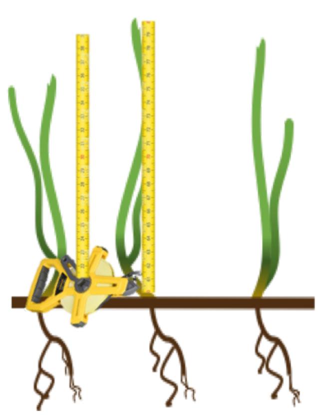
25% cover algae clumped (ignore algae outside original plot area)

25% cover algae randomly spaced (in original plot area)

Correctly estimating % cover of algae takes practice. Make sure that you and your team are calibrated and quantify % cover with variation.

- Maximum canopy height

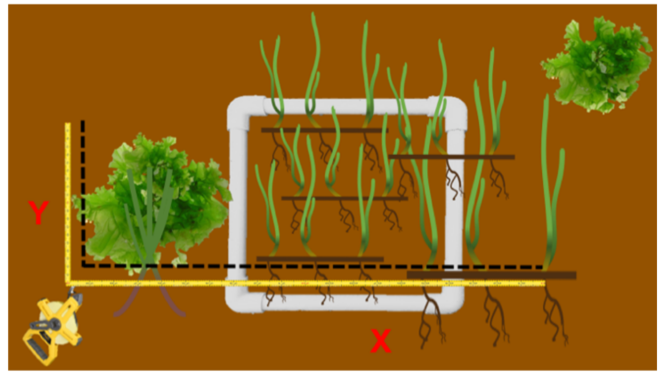
Identify the longest leaf in the plot area and measure its length using a transect tape starting at the base of the leaf/node.

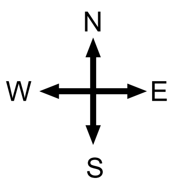


MONITORING

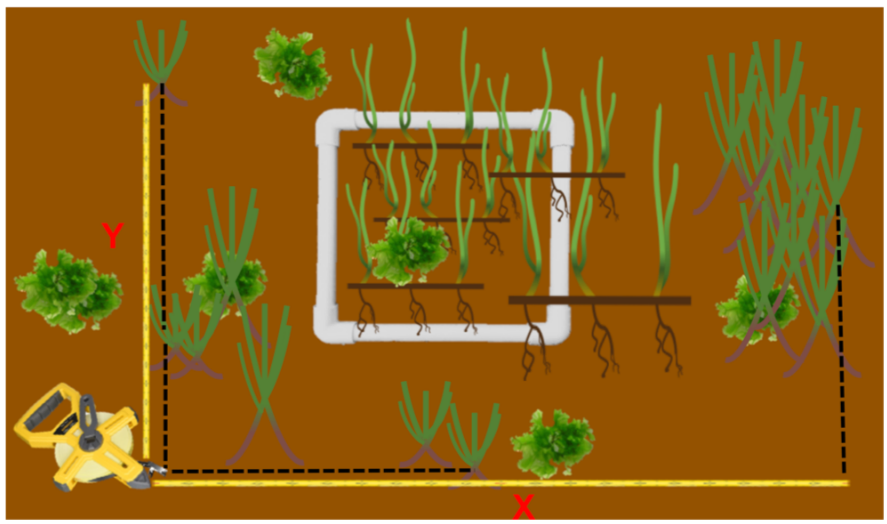
Total plot area (X & Y of the plot)
This is defined as the longest two distances (X*Y) growing from the original plot area. First identify the original plot area, then search farthest shoot extending away from the original plot area in the X direction (could be West/East) and then again in the Y direction (could be North/South).

Example 1.





Example 2.



If you are interested in the colonization of fishes and invertebrates into the restored plots then we suggest both trapping in the plots (using baited minnow traps and shrimp pots) and collecting one shoot per plot to process in the lab for mesograzers*.

The above photos are an assortment of mesograzers that were identified, sorted, sized and weighed for our restoration in Elkhorn Slough—visually demonstrating the potential diversity and abundance of mesograzers in eelgrass restoration plots.

FURTHER RESOURCES

Water Quality:

To look up the water quality in your area try the below links.

- Environmental Protection Agency: National Aquatic Resource Surveys
  - https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys
- USGS Water Quality Data
  - https://water.usgs.gov/owq/data.html#USGS
- National Estuarine Research Reserve System Centralized Data Management Office
  - http://cdmo.baruch.sc.edu
- California Water Boards State Water Resources Control Board
  - https://www.waterboards.ca.gov/resources/data_databases/

Permitting & Guidelines:

To learn about the permitting/certifications required for your field site try the below links.

- AAUS Scientific Diving Certification/Institutions
  - https://www.aaus.org
- NOAA Fisheries California Eelgrass Mitigation Policy and Implementing Guidelines
  - http://www.westcoast.fisheries.noaa.gov/publications/habitat/california_eelgrass_mitigation/Final%20CEMP%20October%202014/cemp_oct_2014_final.pdf
- U.S. Fish & Wildlife Permitting
  - https://www.fws.gov/southeast/our-services/permits/
- National Marine Sanctuary Permitting
  - https://sanctuaries.noaa.gov/management/permits/welcome.html

GLOSSARY

Aquatic angiosperm: aquatic flowering plant

Turbidity: the degree to which water looses its transparency due to suspended particles in the water column.

Oligotrophic: nutrient poor (with typically high oxygen levels)

Eutrophic: nutrient rich, high nutrient levels can increase primary production and decomposition which can result in a decrease in oxygen (O_2) availability and lead to hypoxia or anoxia.

Hypoxia: Low oxygen levels in body of water

Anoxia: Close to zero oxygen levels in body of water

Ephemeral: short-lasting, seasonal

Macroalgal bloom: rapid increase or accumulation of algae in a system. Typically fueled by nutrient pulses.

Light attenuation: reduction in the intensity (penetration) of light through a medium (i.e. water) due to absorption and scattering of photons.

AAUS Scientific Certification: "The mission of the American Academy of Underwater Sciences (AAUS) is to advance and facilitate safe and productive scientific diving…. Organizational membership includes colleges and universities, government agencies, museums and aquaria, environmental and archaeological consulting firms, and community science groups sharing a common thread of the use of diving as a research tool and a commitment to the health and safety of scientific divers. AAUS produces consensual standards for the training and certification of scientific divers and the operation of scientific diving programs…" Source: www.aaus.org

Mesograzers: small invertebrate herbivores.

WORKS CITED

Hughes B.B., Eby R, Van Dyke E. et al (2013) Recovery of a top predator mediates negative eutrophic effects on seagrass. PNAS 110:15313–15318

Maxwell, P. S., Eklöf, J. S., van Katwijk, M. M. et al (2017), The fundamental role of ecological feedback mechanisms for the adaptive management of eelgrass ecosystems – a review. *Biol Rev*, 92: 1521–1538.

Mayor, Á. G., Kéfi, S., Bautista, S. et al (2013).Feedbacks between vegetation pattern and resource loss dramatically decrease ecosystem resilience and restoration potential in a simple dryland model. *Landscape Ecology*, *28*(5), 931–942.

Nyström, M., Norström, A., Blenckner, T. et al (2012). Confronting Feedbacks of Degraded Marine Ecosystems. *Ecosystems, 15*(5),695-710.

Suding, K. N., Gross, K. L.,&Houseman, G. R. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution*,*19*(1), 46–53.

Thom, R.M., Southard, S.L., Borde, A.B. et al. Estuaries and Coasts (2008) 31: 969.

Van Der Heide, T., Van Nes, E. H., Geerling, G. W. et al (2007). Positive feedbacks in eelgrass ecosystems: Implications for success in conservation and restoration. *Ecosystems*,*10*(8), 1311–1322.

van Katwijk, M. M., Thorhaug, A., Marbà, N. et al (2016). Global analysis of eelgrass restoration: The importance of large-scale planting. *Journal of Applied Ecology*,*53*(2), 567–578.