02 INFORMATION ABOUT PRINCIPAL INVESTIGATORS/PROJECT DIRECTORS(PI/PD) and co-PRINCIPAL INVESTIGATORS/co-PROJECT DIRECTORS

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Race:
(Select one or more)
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- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
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TITLE OF PROPOSED PROJECT **Drivers and Passengers of Shifts in Benthic Foundation Species Dominance**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 535,373	36 months	07/01/14	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
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CO-PI/PD				
CO-PI/PD				
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CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), drug-free workplace, debarment and suspension, lobbying activities (see below), nondiscrimination, flood hazard insurance (when applicable), responsible conduct of research, organizational support, Federal tax obligations, unpaid Federal tax liability, and criminal convictions as set forth in the NSF Proposal & Award Policies & Procedures Guide,Part I: the Grant Proposal Guide (GPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Conflict of Interest Certification

When the proposing organization employs more than fifty persons, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Conflict of Interest:
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that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the organization's expenditure of any funds under the award, in accordance with the organization's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent), is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

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(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:
(1) No Federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

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Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:
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(2) building (and any related equipment) is covered by adequate flood insurance.

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(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

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(This certification is not applicable to proposals for conferences, symposia, and workshops.)

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The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

CERTIFICATION PAGE - CONTINUED

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Federal Tax Obligations

When the proposal exceeds $5,000,000, the Authorized Organizational Representative (or equivalent) is required to complete the following certification regarding Federal tax obligations. By electronically signing the Certification pages, the Authorized Organizational Representative is certifying that, to the best of their knowledge and belief, the proposing organization:
(1) has filed all Federal tax returns required during the three years preceding this certification;
(2) has not been convicted of a criminal offense under the Internal Revenue Code of 1986; and
(3) has not, more than 90 days prior to this certification, been notified of any unpaid Federal tax assessment for which the liability remains unsatisfied, unless the assessment is the subject of an installment agreement or offer in compromise that has been approved by the Internal Revenue Service and is not in default, or the assessment is the subject of a non-frivolous administrative or judicial proceeding.

Certification Regarding Unpaid Federal Tax Liability

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By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that the corporation has no unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

* EAGER - EArly-concept Grants for Exploratory Research
** RAPID - Grants for Rapid Response Research

PROJECT SUMMARY

Overview:

This research seeks to address the causes behind shifts in the dominant foundation species in the nearshore subtidal of the Gulf of Maine. While this system has historically been dominated by kelps, the past thirty years we have seen multiple shifts in the identity of the dominant foundation species. Most, but not all, of these shifts have occurred in wave sheltered areas. It is unclear whether these shifts are due to kelp-removing disturbances or competition by both invasive and formerly subdominant turf algae. Preliminary data collected around Appledore Island, Maine, suggests four hypotheses:

H1: Shifts from kelps, the dominant foundation species, to turfs will continue throughout the Gulf of Maine as turfs colonize areas of kelp removal.

H2. Shifts in dominant foundation species identity are driven by large-scale removal of kelps, not exclusion by competitors.

H3: Lower kelp recruitment will enable competitor success in the field.

H4. Kelp populations are maintained in wave disturbed areas by their ability to colonize during periods following intense winter disturbance.

Intellectual Merit :

Nearshore coastal ecosystem impacted by humans often see radical shifts in dominant space-holding habitat forming foundation species. These shifts may be from native species to non-native or from one native species to a formerly competitively subordinate species. Coral reefs may become algae beds. Kelp forests may become mats of red algal turfs. Large shifts in habitat morphology, food provision, and more can have cascading consequences for community structure, ecosystem function, and service provision.

The proximate mechanism behind why these shifts occur is often unclear. Theory suggests two hypotheses: 1) environmental change facilitates shifts in competitive hierarchies or the introduction of superior competitors and 2) the ’passenger’ hypothesis, which states that new dominant foundation species are merely filling an empty niche left by the removal of the former foundation species which lacks the ability to recolonize and maintain itself in the disturbed area.

We will test these hypotheses via a series of seasonal kelp removals coupled to monitoring of kelp and algal recruitment, an observational experiment to examine where we see changed from kelps to turfs, and an experiment to examine correlation of patterns of monthly recruitment with patterns of wave disturbance.

Broader Impacts :

This project will provide training for one graduate student and two to six undergraduates over the course of the grant. Undergraduates will be mentored towards developing honors theses. In addition to developing their research projects, students will be active participants in talking about this work via online social media, documenting their observations of the natural history of the subtidal Gulf of Maine. Data from kelp removals will be shared with a global kelp removal experimental network. Records of kelp abundances from control plots will be shared with the Northeastern Regional Association of Coastal Ocean Observing Systems Sentinel Monitoring Program.

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For font size and page formatting specifications, see GPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

A. Introduction

Marine ecosystems are frequently defined by foundation species – species that dominate space forming biogenic habitat for the organisms around them (*sensu* Dayton, 1972). Changes in foundation species identity can have large effects on ecological community structure, function, and service provision (Altieri & van de Koppel, 2014). Kelps, large brown algae from the order Laminariales, have traditionally served as the dominant foundation species in much of the shallow nearshore of the Gulf of Maine (Johnson & Skutch, 1928; Witman, 1987; 1988; Steneck *et al.*, 2002; 2004). More recently, we have witnessed great changes in the identity of the dominant foundation species in many areas of this ecosystem over the past few decades – from coralline barrens (Steneck *et al.*, 2013) to *Codium* meadows (Harris & Tyrrell, 2001; Levin *et al.*, 2002; Mathieson *et al.*, 2003) to, more recently, algal turf beds (Newton *et al.*, 2013; Steneck *et al.*, 2013, and see preliminary observations).

In order to understand the future of systems experiencing rapid shifts in the identity of their dominant foundation species, we need to develop a mechanistic understanding of *why* foundation species identities might change. To what extent are human altered biotic or abiotic conditions responsible? Are shifts in foundation species identity due to changes in the competitive ability of subdominant incipient 'foundation' species in the system, or are alternate foundation species merely moving in to areas that are now open due to shifts in the environment removing previous dominant foundation specie? This latter hypothesis can be seen as a variation of the passenger hypothesis for species invasions (Gurevitch & Padilla, 2004); the passenger hypothesis provides a powerful framework to experimentally evaluate the causes of shifts in species composition. ***Here I propose to determine whether changes in the identity of dominant subtidal foundation species in the nearshore Gulf of Maine are determined by changes in disturbance regimes versus shifts in the impact of competitors.***

While the passenger hypothesis is typically applied to species invasions, it has wide applicability for thinking about any observed shift in foundation species. The passenger hypothesis states that the loss of native species and subsequent replacement by invasive competitors is not due to these invaders outcompeting and eliminating native competitors. Rather, environmental perturbations – typically human driven – reduce the abundance of resident native species and open up new niche-space for incoming exotics (Gurevitch & Padilla, 2004; MacDougall & Turkington, 2005). The passenger hypothesis has been demonstrated in both terrestrial and aquatic systems (MacDougall & Turkington, 2005; Glasby, 2013). The passenger hypothesis does not always accurately describe why exotics replace native species, however; sometimes a new exotic species is simply a competitive dominant (White *et al.*, 2013). Furthermore, the passenger hypothesis and shifts in the competitive landscape are not mutually exclusive (Bulleri *et al.*, 2010; Bauer, 2012). While anthropogenic disturbance may remove a native species and enable the rapid spread of an invader, the new invader may also prove to be competitively dominant to natives, suppressing their recovery.

The idea of environmental or human-driven perturbations opening vacant niche-space and thus changing the long-term identity of the dominant foundation species has broad applicability outside of invasion biology. Even normally subdominant native species can be passengers to change. For example, due to declines caused by woolly adelgids, Hemlock is being replaced by competitively subdominant birch in many New England forests (Orwig *et al.*, 2002). The competitively dominant shallow-water seagrass *Zostera marina* in North Carolina is being replaced by the competitively subdominant *Halodule wrightii* (Micheli *et al.*, 2008) as waters warm. Moving into kelp dominated ecosystems, removal of kelps in Baja California due to a strong El Niño enabled the system to shift from dominance by the giant kelp *Macrocystis pyrifera* to dominance by subcanopy kelps (Edwards, 2004; Edwards & Hernández-Carmona, 2005; Edwards & Estes, 2006). Only removal of the new foundation species enabled giant kelp recolonization.

Kelp ecosystem serve as a particularly relevant testing ground for differentiating between human impacts opening up vacant niches versus shifts in the competitive landscape as a driver of foundation species shifts. The past two decades have witnessed a series of shifts in community composition in many temperate marine ecosystems away from kelps towards subdominant turf algae – short algal species that obtain high densities and alter the habitats around them (*sensu* Connell *et al.*, 2014). In Norway, *Saccharina latissima* is being replaced by ephemeral algae in wave protected habitats, likely due to interactions between eutrophication and climate change (Moy & Christie, 2012). This switch coincides with a period of recovery for kelps after large-scale disturbance by sea urchins, much like in the Gulf of Maine (Norderhaug & Christie, 2009). In South Australia, urbanization, sedimentation and rising CO_2 levels all appear as major contributors to switches from kelp to turf systems (Gorgula & Connell, 2004; Connell *et al.*, 2008; Connell & Russell, 2010). Similarly, turfs have displaced several functional groups algae in the Mediterranean (Airoldi, 1998; Airoldi & Virgilio, 1998; Airoldi, 2000). Most notably, dominant large structure forming subtidal fucoids from the genus *Cystoseira*, tend to be replaced in areas of human disturbance, with good experimental support for a shift consistent with the passenger hypothesis (Benedetti-Cecchi *et al.*, 2001; Irving *et al.*, 2009). Turfs in all three of these regions have achieved dominance due to an initial elimination of kelps due to human disturbance (e.g., grazer predation release, urban sedimentation, etc.) and in some places, altered turf competitive abilities allow them to suppress kelp recovery. It is unclear whether either mechanism is more prevalent globally.

The Nearshore Gulf of Maine: Passenger of Change?

The Gulf of Maine and Nova Scotia in the late 20th and early 21st centuries has witnessed several different shifts away from kelps as the dominant foundation species (reviewed in Steneck *et al.*, 2013) which echo the ideas contained in the passenger hypothesis. Overfishing of cod and other predatory groundfish led to an increase in urchin abundance and impact in the subtidal (Steneck, 1997). This trophic cascade transformed many areas in the Gulf and Nova Scotia into urchin barrens dominated by coralline algae (Scheibling, 1986; Scheibling *et al.*, 1999; Steneck *et al.*, 2004). While urchin grazing may have been reduced by urchin fisheries (Andrew *et al.*, 2002), disease in Nova Scotia (Scheibling & Stephenson, 1984; Scheibling & Gagnon, 2009; Scheibling & Lauzon-Guay, 2010), and consumption of juvenile urchins by small crustaceans (McNaught, 1999), urchins were still able to play a major role in further system shifts. Urchin consumption coupled with the impact of an invasive kelp-covering bryozoan facilitated the invasion of the green alga *Codium fragile;* many areas shifted to *Codium* meadows (Levin *et al.*, 2002; Sumi & Scheibling, 2005). While current *Codium* abundances appear far lower than historic peaks (see preliminary data), invasive turf species such as *Bonnemaisonia hamifera*, *Neosiphonia harveyi,* *Heterosiphonia japonica* are now in high abundance in many previous kelp-dominated areas. The phenomenon of foundation species replacement is not limited to exotic species, however. During the same period of time, massive recruitment of mussels, often, but not exclusively, on turfs and bare patches, altered subtidal community dynamics (Witman *et al.*, 2003). Similarly, native red algal turf species such as *Chondrus crispus* are currently extending down into the subtidal, (Steneck *et al.*, 2013). This has led to a transformation of many areas of the subtidal (Fig. 1).

Curiously, kelps still remain dominant in many wave-exposed habitats despite these shifts. Kelps are even recolonizing some formerly depopulated areas (Steneck *et al.*, 2013), despite losing ground to turfs in still others. Kelp beds can often be found just a few meters away from a turf bed, around a point or on the nearby wave exposed side of an island. While disturbance-driven facilitation of alternate foundation species is an appealing hypothesis, this persistence of kelp. raises questions about whether alternate foundation species have benefited due to disturbance alone, or if the competitive landscape in the Gulf of Maine really is changing.

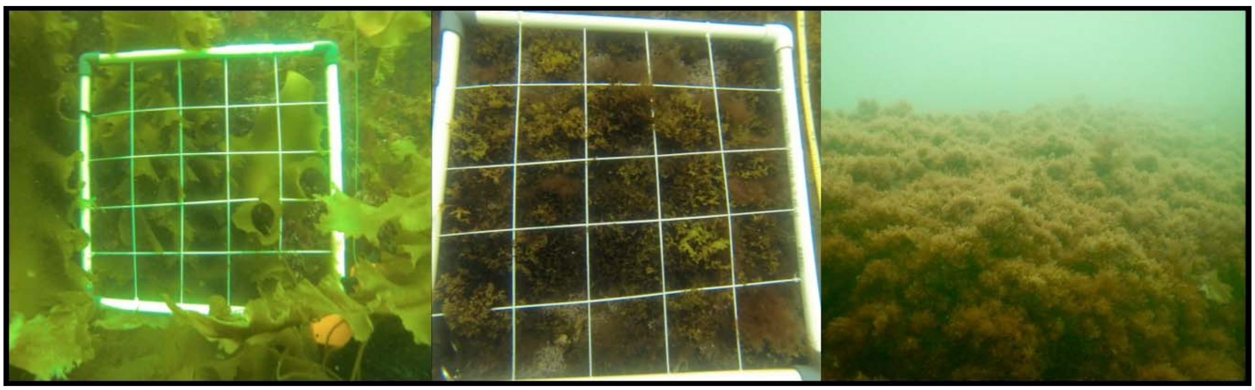

Figure 1: Three observed community states at 7m depth around Appledore Island, Maine. From left to right, we have a quadrat in a wave exposed site dominated by kelps, a quadrat in a site dominated by the native alga *Chondrus crispus*, and finally an site with an area the size of a soccer pitch dominated by the invader *Heterosiphonia japonica*.

Given this history, the nearshore subtidal of the Gulf of Maine represents an ideal candidate system to ask questions about the drivers of shifts in foundation species. Furthermore, this ecosystem has already served as a model system to examine the biological mechanisms that drive the dominance and environmental zonation of foundation species. For example, simple experimental manipulations have shown that foundation species identity along depth gradients is driven by multiple indirect effects of wave energy; kelps dominate the shallows due their ability interfere with encroaching mussels subjected to high flow (Witman, 1987) and high wave energy frees them from herbivory by urchins (Siddon & Witman, 2003). Simple environmental manipulations have elucidated the relative role of light in stymieing algal dominance on rock walls (Miller & Etter, 2008) and the role of small-scale flow differences in shaping zonation on rock walls due to food delivery (Leichter & Witman, 1997). In these and other studies, simple clearing, transplant, and recruitment experiments were the keys to elucidating the mechanisms regulating the dominant foundation species identity.

Thus, the Gulf of Maine is a perfect system to ask questions about causes of contemporary shifts to novel foundation species. Data from my preliminary subtidal observations (see below) suggest that previous kelp removal, rather than the initial competitive abilities of encroaching turf algae, likely drives changes in foundation species dominance. Turfs serve as passengers – at least initially. Kelps are able to remain in the system due to their ability to rapidly recolonize patches opened by winter wave disturbance.

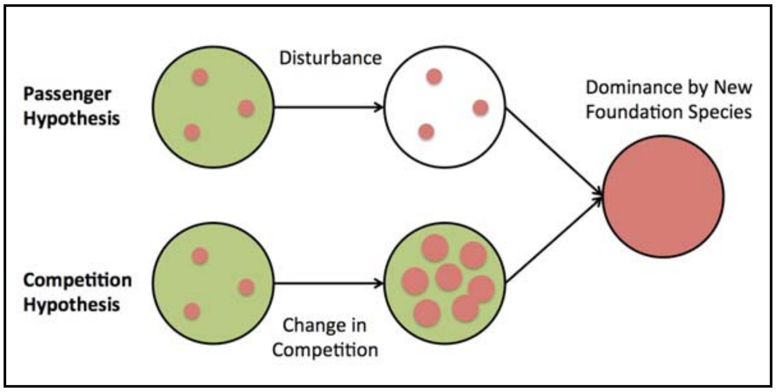

Figure 2: Conceptual overview of alternate outcomes of a kelp clearing experiment. Green is kelp, red is turfs. If turfs are passengers to disturbance, then removal of kelp should result in their ability to spread and dominate a patch. If competition by turfs drives their ability to dominate a patch, then removal should be irrelevant for their final cover.

Here I present a research plan that centers on a series of experimental kelp removals and observations of patterns of community growth and change. In general (Fig. 2), if the passenger hypothesis is driving forward shifts from kelps to turfs or other alternate foundation species, large-scale kelp removals should lead to changes in the identity of the dominant species over time. In contrast, if shifts in competition in nearshore sites are driving changes in foundation species dominance, we should see shifts regardless of treatment.

Coupling observations of change in community structure with experiments at different sites with wave exposure regimes, and monthly algal recruitment measurements will allow me to elucidate the ecological mechanisms behind patterns that I am beginning to see take shape in the Southern Gulf of Maine.

B. Preliminary Observations & Hypotheses

To begin to assess the relationship between kelp and turfs, I surveyed Appledore Island, the Isles of Shoals, Maine in the summer of 2012 working with an undergraduate interested in species invasions at the Shoals Marine Lab (SML). We performed two surveys (Fig. 3) at 6-12m depth using both sides of the island to coarsely look at the effects of wave exposure - East side = wave exposed, West = wave protected (Levin *et al.*, 2002; Byrnes & Witman, 2003). In the first survey, we assessed the percent cover of the dominant kelp, *Saccharina latissima* (hereafter kelp), and the invasive turf alga, *Heterosiphonia japonica*, in thirty 0.25m^2 quadrats at eight sites in June. In a second July survey, to gain an understanding of large-scale patterns of kelps and multiple algal species, we sampled along 40m transects noting

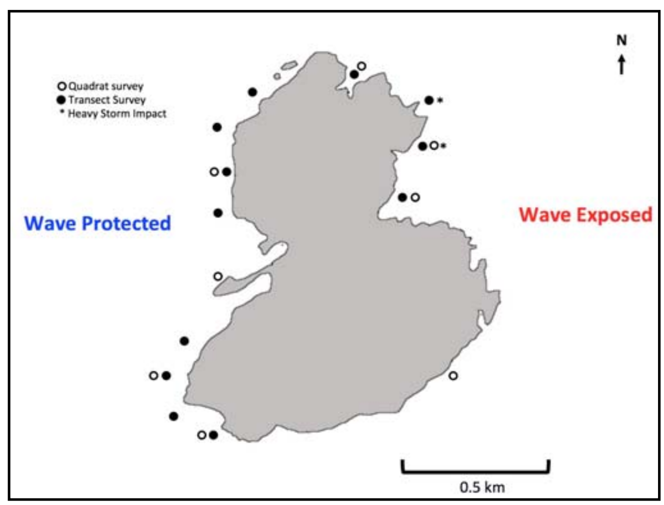

Figure 3: Appledore Island, Maine. Open circles show locations of quadrat surveys and filled circles show locations of transect surveys. Stars indicate areas that were completely scoured by boulders during previous winter storms.

presence or absence of all extant sessile species spaced at 1m intervals on 1m of either side of the transect (80 points) at twelve sites.

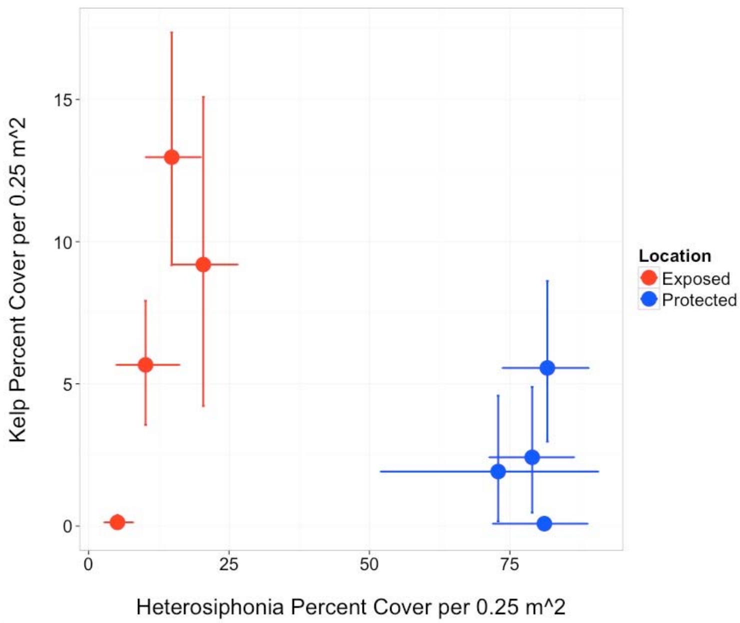

Figure 4: Mean and bootstrapped confidence intervals of kelp and *Heterosiphonia* percent cover at wave exposed (red) and wave protected (blue) sites from 0.25m² photo quadrat samples taken in June.

Broadly, our small-scale survey shows that kelp and invasive turfs occupy different environments. At small scales, kelps are common in wave exposed habitats where *Heterosiphonia* is rare (Fig. 4). Kelps are rare in wave protected sites where *Heterosiphonia* often dominated hundreds of square meters (Fig. 3). The notable exception was a site that received intense wave action and boulder movement during a winter storm; it was bare scoured rock from the mid intertidal to ~15m in June.

This highly disturbed site provided some support for the passenger hypothesis. If large-scale removal of kelp enabled dominance of turfs, then we would predict that *Heterosiphonia* or another turf would come to dominate this site with little recovery from kelps. This is exactly what the data shows. When I resurveyed the site with my student two months later (Fig. 5), the kelp 'removal' site, Norwegian Cove, was still largely absent of kelp but had achieved high cover of *Heterosiphonia*. The basic exposed/protected pattern at other sites remained the same, save at one site that retained high cover of kelp, but experienced a *Heterosiphonia* boom. Thus while this observational evidence from small-scale surveys is suggestive of passenger-like behavior in the system, at least by one species of turf, *Heterosiphonia,* it requires further exploration.

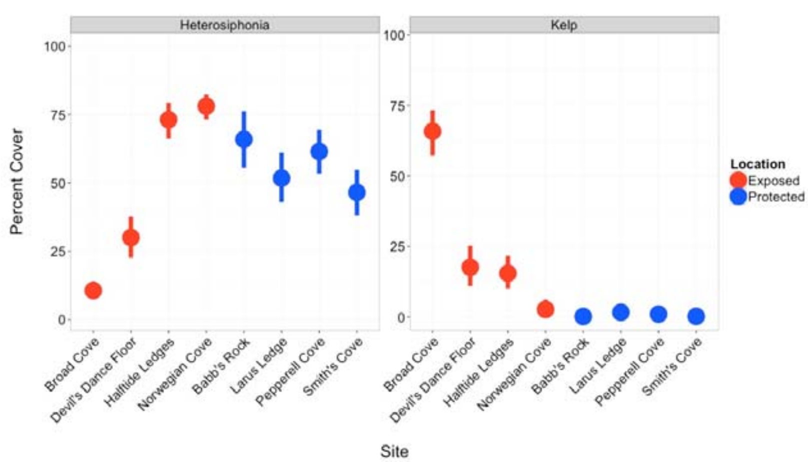

Figure 5: Mean and bootstrapped confidence intervals of percent cover of *Heterosiphonia* and kelp in 0.25m2 quadrats in August at the same sites using the same methods as Fig. 4.

The results differ slightly in my larger-scale transect survey. I surveyed a slightly different pool of sites around Appledore in July (Fig. 3 closed circles). At each site, I noted the presence or absence of all identifiable species under points on either side of a 40m transect spaced every 1m (80 points total). While kelp still shows a distinct environmental pattern, the opposite of *Codium*, *Heterosiphonia* appears to be a ubiquitous understory species (Fig. 6). Curiously, the formerly dominant *Codium* appears to now be nearly absent, replaced by *Heterosiphonia* at many sites. Note also that in July surveys *Heterosiphonia* was at 100% in the aforementioned completely scoured site, indicating that its colonization was rapid. Furthermore, the native turf *Chondrus crispatus* also showed high abundances on exposed sites. Was it excluded by *Heterosiphonia* from protected sites? The answer to this question is unclear. While broad-brush survey method provides some complementary support to the small-scale surveys above, the prevalence of turfs at exposed sites suggests that, while perhaps not abundant in small-scale intensive samples, they are often at least present in sites where kelps are the dominant foundation species.

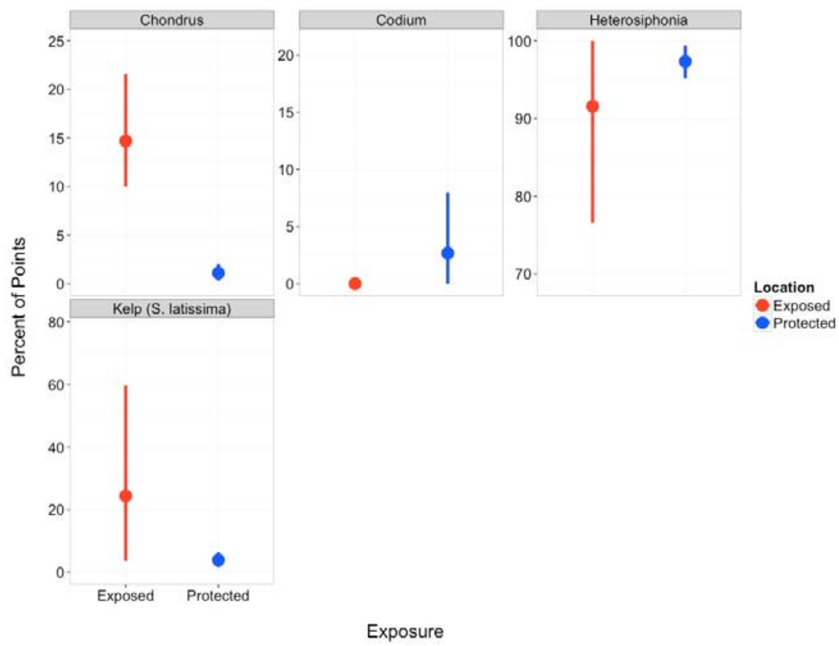

Figure 6: Mean and bootstrapped confidence interval of percent cover out of 80 points of three 'turf' species (*Chondrus*, *Codium*, and *Heterosiphonia*) and kelp averaged at all exposed (red) and wave protected (blue) transects. Points were on either side of 40m transects.

These preliminary observations and the literature suggest several clear testable hypotheses that address whether shifts away from kelp are due to passenger-like behavior of the system. ***H1: Shifts from kelps, the dominant foundation species, to turfs will continue throughout the Gulf of Maine as turfs colonize areas of kelp removal.*** This hypothesis is based on observational data: the shift in the community at the exposed presumably formerly kelp dominant Norwegian Cove. It matches our knowledge of shifts from kelps to turfs in Southern Australia and Norway. If alternate foundation species dominance is driven by kelp removal, then community shifts could progress in a ratcheting fashion corresponding with major disturbance events – driven by either physical conditions (e.g., boulder disturbance) or biological conditions (e.g., urchin outbreaks). However, if H1 is falsified, an alternate hypothesis suggests that wave exposure may maintain kelp population abundances (see H4). ***H2: Shifts in dominant foundation species identity are driven by large-scale removal of kelps, not exclusion by competitors.*** Kelp was not present in wave exposed areas, removal of kelp has previously facilitated *Codium* invasions (Levin *et al.*, 2002), and the two scoured sites witnessed explosions of *Heterosiphonia* but little kelp recovery. This pattern is consistent with the passenger hypothesis. ***H3: Lower kelp recruitment will enable competitor success in the field.*** While turfs are present on the exposed side of Appledore, they are not dominant. The protected side has a history of grazing damage and heavy blanketing by *Codium* and mussels.

This, turf invasion may have been merely facilitated by low recruitment, rather than superior invader competitive abilities. ***H4. Kelp populations are maintained in wave disturbed areas by their ability to colonize during periods following intense winter disturbance.*** Saccharinid kelps can produce new sporophytes at a variety of temperatures, but typically perform better when it is cold (Bartsch *et al.*, 2008). In Europe, they colonize in the winter and spring (Parke, 1948) and in the Gulf of Maine fill in gaps after fall-spring disturbances (Witman, 1987). Now we only find them in wave exposed areas. If recruitment is higher in these areas after winter storms, then we should see high recruitment immediately following intense storm events.

C. H1: Shifts from kelps, the dominant foundation species, to turfs will continue throughout the Gulf of Maine as turfs colonize areas of kelp removal.

If turfs continue to colonize areas where kelp has been or will be removed, then I would predict that turf dominance should increase over time and space in the Gulf of Maine. Given the dynamics of turfs in other sites around the globe (Gorgula & Connell, 2004; Connell *et al.*, 2008; Connell & Russell, 2010; Moy & Christie, 2012; Connell *et al.*, 2014) as well as the rapid spread of *Heterosiphonia* (Schneider, 2010; Newton *et al.*, 2013; Savoie & Saunders, 2013) and increase in subtidal *Chondrus* (Steneck *et al.*, 2013), shifts in foundation species in the shallow subtidal appear increasingly likely. The observations I have from Appledore in the summer of 2013 provides only a snapshot of kelp and turf dynamics. To evaluate the hypothesis that turfs will continue to increase in dominance, I need to sample the same sites over time and increase the geographic scope of my sampling.

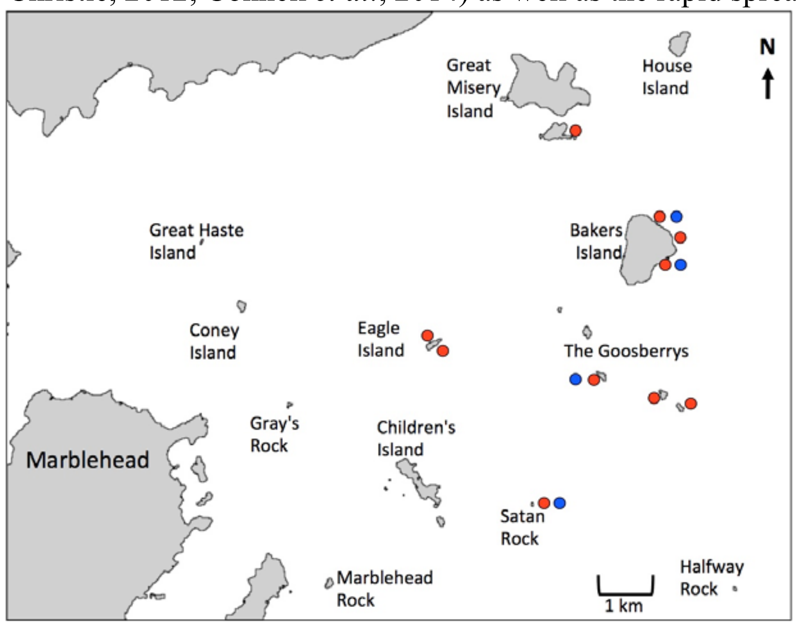

Figure 7: Map of Salem Sound. Sites to be used for H1, H2 and H3 are marked in red. Sites for recruitment sampling in H4 are in blue.

First, I plan to repeat the sampling I conducted in the summer of 2013 at Appledore Island, Maine, at the same sites. Second, to test whether this pattern is unique to Appledore or whether turfs or other foundation species are increasing in dominance in the southern Gulf, I will setup a parallel observational study in Salem Sound, Massachusetts (Fig. 5, red sites for sampling) where I have begun to work out of Salem State's Cat Cove Marine Laboratory.

In Salem Sound, sites around Bakers Island and The Goosberrys show variation in kelp and turf abundance that matches their exposure to waves from the open ocean to the west. To verify our classification of wave exposed versus unexposed based on observations of exposure to open swell at sites in Salem Sound, I will deploy three pre-weighed standardized 6cm diameter x 4cm height dental cement (gypsum) blocks (Leichter & Witman, 1997) for two weeks during July of year 1 and again in November.

To evaluate the hypothesis that turfs will increase their dominance within the Gulf, I will sample sites for three years (year 1 at Appledore sites is complete) during the early to mid-Summer. At all sites, I will employ two sampling methods used previously to differentiate between dominance by a species versus its presence as a subdominant. At each site, I will run three 10m transects placed on hard substrate at a depth of between 6-12m and take photographs of strung $0.25m^2$ quadrats for later assessment of the percent cover of kelps and turfs using ImageJ processing software back in the lab. I will also sample points on either site of a 40m transect with points spaced 1m apart (80 points). Under each point, I will record the identity of all species observed and the type of substrate. This is the protocol developed by the Santa Barbara Coastal LTER for sampling benthic community structure in kelp forests (Byrnes *et al.*, 2011).

Coupling H1 with current observations, I can make several predictions as to the results of small-scale surveys that can be evaluated with simple regression models using the data collected. 1) Protected sites, which have been low in kelp cover due to grazing and invasive species, are likely to already be dominated by turfs or alternate foundation species already and will continue to be dominated by alternate foundation species. 2) Exposed sites will initially have low cover of alternate foundation species. Over time, they will lose kelp cover and gain turf cover. 3) Areas that experience a particularly large loss of kelps between years will be dominated by turfs in the following year.

If turfs are functioning as passengers rather than superior competitors, I expect that while there will be a negative correlation between kelp and turf abundances in small-scale surveys, I will see no relationship between kelp and turf abundances in transect surveys. Rather, turf species will tend to be at moderate to high cover, regardless of kelp abundance. Different species may still respond differentially to environmental conditions, however.

It is possible that we may falsify H1 for exposed sites, but not protected ones. While my preliminary observations at Norwegian Cove on Appledore suggest that encroachment should proceed even in wave exposed areas, observations in kelp forests in Norway subjected to turf increases suggest otherwise. There, kelps persist in wave exposed habitats (Sogn Andersen *et al.*, 2011). Thus, one outcome of this observational experiment could be a need for a more fine-scale mechanistic understanding of the system, addressed in H2-H4.

D. H2: Shifts in dominant foundation species identity are driven by large-scale removal of kelps, not exclusion by competitors. If the dominance by alternate foundation species is due to their taking advantage of disturbance rather than changes in competition, then only large-scale removal of kelp should trigger a flip in foundation species dominance. If competition is the driver, then a removal should be unimportant; areas with some cover of alternate foundation species should lose kelp over time. If both competition and disturbance work synergistically, then all sites in protected areas should lose kelp, while only removal sites in wave-exposed areas should flip their dominant foundation species. Therefore, to test H1, I will conduct a kelp removal experiment at sites varying in wave exposure.

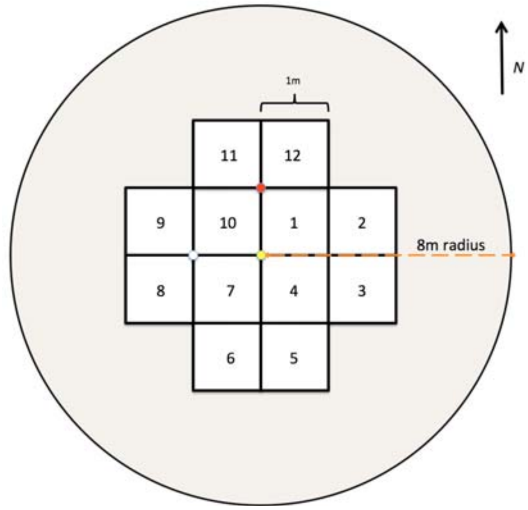

Figure 8: Layout of sampling quadrats within a kelp removal plot.

I will conduct the experiment at sites at both Appledore Island (3 exposed – NW and SW, 3 protected – NW and SW) and Salem Sound (10 sites of varying exposure) (Fig. 7) between 6-12m to match ongoing work from H1. Each site will have one 8m radius kelp removal plot, so that the central $16m^2$ can be sampled without edge effects. In preliminary trials, kelps at the edge of the clearing were able to fall 3-4m inside of the edge of the cleared zone. An 8m radius provides a wide buffer to simulate a larger-scale kelp-removing disturbance for the center of the plot. For removals, all *Saccharina latissima* in an 8m radius from the center of the removal plot will be trimmed above the holdfast. As the meristem of *S. latissima* is at the top of its stipe (Gerard, 1987); it will not regrow if trimmed just above the holdfast. Each site will also contain three control plots. I am using three controls rather than one due to potentially high levels of stochastic change, even within a site. If, for example, an urchin front moves through or a fisherman drags gear on a site, I will not have an accurate baseline against which I can compare the removal plot (n.b. this has happened in preliminary trials).

I will run the experiment in late June starting in year one. *Heterosiphonia* increases greatly in abundance over the course of the summer (per obs.) while kelps grow and reproduce little (Bartsch *et al.*, 2008). Results suggesting that disturbance, not competition, driving results in this trial summer trial would provide strong support for H2. See H3 below for more on recruitment.

At each site, I will run a 30m transect parallel to shore in an area that has moderate to high kelp abundances. Kelp presence before the experiment is essential in order to provide a valid test of the hypothesis. Plots will be centered at 0, 10, 20, and 30m. The location of the removal plot along the transect will be selected at random. I will sample each plot before removal, two months following, and during July (peak growing season) of the following year. Plots will be marked in their center, 1m to the north, and 1m to the West to facilitate orientation of quadrats and ease in re-finding plots after winter overgrowth. I will sample 12 $1m^2$ quadrats in around each point (Fig. 8), counting the abundance of all solitary kelps and other algae and sessile invertebrates in each quadrat in addition to using using a 5x5 grid on a strung quadrat to quantify number of points of all other sessile algae and invertebrates (e.g., *Heterosiphonia*, other turfs, or colonial tunicates). I will resample plots again after two months and again during July (i.e., peak growing season) of the following year. Data will be averaged at the plot level, as I am asking a question does not concern plot level variation; results for main effects should be qualitatively equivalent to more complex models incorporating this information.

As data on both % cover and abundance is likely to be overdispersed and bounded at 0, thus violating assumptions of ANOVA, I will analyze all results using a generalized linear model mixed model with the appropriate link function and error distribution for the data (e.g., Gamma or Quasi-Poisson for kelp count data with a log or linear link, binomial with a logit link for percent cover), depending on the type of data and shape of the relationship between initial and final abundances of measured quantities (Bolker *et al.*, 2009; O'Hara, 2009). The underlying linear component (for any link function and error distribution) of the model for abundance of any species at time t will be as follows with 1|Area denoting a random effect of area (Appledore or Salem Sound) on the intercept, and the same with site nested in Area.

$$\text{Abundance}_t \sim \text{Treatment} + \text{Exposure} + \text{Treatment*Exposure} + (1|\text{Area}) + (1|\text{Site in Area})$$

I will evaluate whether each set of coefficients contributes to Abundance at time t using $\chi 2$ Likelihood ratio tests after fitting using maximum likelihood, but will evaluate coefficients using a model fit using REML (Zuur *et al.*, 2009). Note, if ANOVA assumptions are met, I will used a mixed model ANOVA using the same model with type II sums of squares to accommodate the unbalanced design (Langsrud, 2003) for the sake of simplicity. I will use this model to look at responses of kelp, *Chondrus*, *Heterosiphonia*, and any other conspicuous species to the treatment. H2 suggests that I should see a main effect of Treatment, with turfs having higher abundances in removal plots and kelps having lower abundances. There may also be a main effect of Exposure. If competition is driving the system, there should be no effect of either treatment. If competition is suggested, the following model model:

$$\text{Abundance}_t \sim \text{Treatment} + \text{Abundance}_{\text{turfs at t-1}} + \text{Treatment*Abundance}_{\text{turfs at t-1}} + (1|\text{Area}) + (1|\text{Site in Area})$$

should have a lower AICc that the previous model. Here, initial abundance of turfs determines their final cover. Turfs should have a positive effect on themselves and a negative effect on kelp. If both competition and disturbance are operating synergistically, there should be an interaction between treatment and exposure in the initial model, with protected sites having low kelp and high turf cover and exposed sites only flipping to turfs in removal sites.

E. H3: Lower kelp recruitment will enable competitor success in the field. The experiment for H1 tests the effect of kelp removal during a period of low kelp recruitment. Thus, it provides a strong test to falsify the competition hypothesis. If turfs are able to take over plots due to the open space created by disturbance, and not superior competitive abilities, then kelp recruitment to removal plots should stymie their advance. Conducting a removal trial starting just before kelp recruitment increases provides a strong test of H2: that lower kelp recruitment will enable competitor success. Therefore, I will not only conduct a removal, but also model the effect of kelp recruitment on community response.

I will repeat the kelp removal from H1 using the same techniques, but will initiate it in the fall (September/October). Due to accessibility (the Shoals Marine Lab closes in late August), I will only run this experiment at sites at Salem Sound near the initial manipulation. Plots will be resampled the following July. I will repeat the experiment in Year 2-3 in order to get a wider range of kelp recruitment values.

I will use standard methods to assess kelp recruitment (Andersen, 2013) during the experiment. Briefly, I will bolt three 20cmx20cm roughened plexiglass panels to the substrate at 0 and 6m away from the center of the clearing at each site. Panels will be removed and kelp recruits will be counted in November, May, and July. This timing is due both to fall and spring being periods of high kelp recruitment and logistical constraints of winter access to sites. While it will invariably incorporate some post-settlement processes (competition, microherbivory), the abundances of recruits will give me an accurate estimate of the potential for new kelps to colonize the system. Kelp recruits and, where possible, recruits of other species will be enumerated under a dissecting scope back in the lab. These will give me an integrated number of recruits over the season (sum all panels). The edge numbers will better indicate site-level recruitment and the center numbers will indicate recruits reaching the center of the plot. If the numbers are highly collinear (Pearson correlation > 0.8), I will pool both panels. Otherwise, I will model results using a modified version of the previous generalized linear mixed model and evaluate it using the same techniques:

$$\text{Abundance}_t \sim \text{Treatment} + \text{Recruitment}_{center} + \text{Recruitment}_{edge} + \text{Treatment*Recruitment}_{center} + \text{Treatment*Recruitment}_{edge} + (1|\text{Year}) + (1|\text{Site})$$

If disturbance, not competition, drives the switch from kelps to alternate foundation species, I would expect an interaction between treatment and one or both recruitment variables. It is possible that kelp removal *per se* determines the abundance of species, and recruitment by kelps does not alter the outcome of colonization by turfs or other alternate foundation species post-disturbance. This pattern would be indicative of the scenario where the passenger hypothesis interacts with competition. In this case, I would expect that only treatment would matter or that the initial treatment*exposure model described in H2 would both have a lower AICc than this model and b) show an effect of exposure rather than recruitment *per se*. If competition is the sole driver of state shifts, then a model incorporating initial turf abundance and treatment (also described in H2) should have a lower AICc and greater explanatory power than this model. This results would provide evidence that cover by turfs and loss of kelps after one year would depend on turf initial cover.

F. H4. Kelp populations are maintained in wave disturbed areas by their ability to colonize during periods following intense winter disturbance. To understand the mechanistic role post-disturbance recruitment of the dominant and subdominant foundation species plays in maintaining its population, I need to sample recruitment of species before and after major disturbance events. Large disturbance events are not predictable. Therefore, I will sample recruitment at regular intervals in order to capture the impact of pulsed events.

At four removal sites from H2 in Salem Sound (blue circles in Fig. 4), I will add three additional panels at 6m from the center of the plot. I am limiting this effort to four sites due to the logistical difficulties of accessing sites in winter. To generate a larger range of recruitment values and wave height, I will run this study for two years. Panels will be replaced monthly and all recruits of all identifiable species will be enumerated under a dissecting scope. Each month, I will assess the maximum significant wave height using NOAA buoy 44029 several miles to the east of Salem Sound as a measure of wave disturbance. After two years, I will then fit a variable slope generalized linear mixed model with a linear or log link (depending on linearity) function to evaluate the correlation of wave height with recruitment and evaluate it as above. The model is:

$$\text{Recruits} \sim \text{Wave Height} + (1+\text{Wave Height} \mid \text{Site})$$

Note that the effect of waves is allowed to vary randomly by site in addition to the intercept. Angle of the site with respect to open-ocean, nearby islands, being shadowed by Cape Ann, etc. all may affect how wave exposure is experienced at a site. Therefore, this model will allow me to not only understand the correlation of wave height with recruitment, but also the degree of variability in its correlation at different sites. If recruitment correlates with disturbance, then the main effect of wave height should be different from 0.

One prediction of this hypothesis is that kelps are better at colonizing during periods of high disturbance than alternate foundation species. I will perform the same recruitment analysis for other species observed on panels to assess the potential for alternate foundation species to be able to colonize bare patches after winter disturbances. My *a priori* expectation is that kelps will both have higher levels of recruitment during the same time of year as high disturbance, and that recruitment will be higher at sites classified as exposed. Protected sites will likely receive little recruitment of kelps. This is due to increased higher light availability enabling better gametophyte recruitment after algal canopies are thinned by wave disturbance. I currently have no expectation regarding recruitment for other species in protected sites. It may follow similar patterns. However, less is currently known about the seasonality of turf species recruitment in the subtidal.

I will also install temperature loggers at each site and replace them monthly. If wave height and water temperature are sufficiently non-collinear (Pearson's $R < 0.8$) I will fit a second alternate model with Temperature and a Temperature*Wave interaction to assess whether waves differ in their effect on recruitment when water temperatures are optimal for recruitment.

G. Broader Impacts and Synergies with Other Projects

Training: This project will involve one graduate student and two undergraduates each summer. I currently plan to accept 1-2 PhD students who have expressed research interests that fit with the general themes contained in this proposal. They will not only be active participants in this project, but will be expected to use it as a jumping off point for their own dissertation work (e.g., using the bare plots for experiments) focusing on subtidal ecology in the Gulf of Maine.

The undergraduates will be drawn preferentially from the pool of UMass Boston students who take advantage of a nascent collaboration between UMB and Salem State's underwater research course or who have completed comparable training elsewhere. The students will be selected from exceptional undergraduates in my marine biology course, and offered the job contingent upon completion of the course. We will provide gear during the course in order to mitigate any financial need. UMB is an urban university with (as of 2010) 55% female and 44% minority enrollment. 50% are first generation college students, and 30-40% come from non-English speaking homes. We also have a several navy veterans with extensive diving experience. *Thus, UMB does not have a typical population of students that have grown up with the socio-cultural trappings that shape so many of the students and faculty in the marine and ecological sciences.* Thus I hope to facilitate a broader diversity of students entering graduate and professional fields in marine ecology.

During July, undergraduates will be asked to develop a small research project involving selective removal of alternate turf species in the edges of removal and control plots. They will implement these projects in August and resample them during September/October removals. If students in year 1 or 2 are rising Sophomores or Juniors, and they wish to continue with research, I will work with them during the school year to facilitate their planning a larger honors project for the following summer. Provided they fit the guidelines, I will help them join the UMB Institute for Maximizing Student Diversity (IMSD). The IMSD provides an annual stipend to non-premed undergraduates interested in biological research.

Outreach and Education: I have been maintaining an active science blog since 2002 (http://imachordata.com, 30-50 pageviews per day, ~200-300 views/day at time of posting any new content) and am very active in talking about science on Twitter (@jebyrnes, currently with ~4.5K tweets and ~2K followers). In addition to using my typical outlets to talk about the science going on in my lab, along with the project graduate student and technician, we will maintain a project blog during the summer. Each week in the field, we'll take photographs of notable observations and accompany them with short write-ups. We'll also conduct interviews with project staff throughout the summer about their role and other research interests. We will work together to attempt to crowdfund (Wheat *et al.*, 2012) additional grad student activities via the #SciFund Challenge (http://scifund.org) which I co-founded and has raised ~$250K for primarily grad student research in the last two years. The real goal of crowdfunding is not the money, but rather providing students with a financial impetus to bring their work to a broader audience. Last, we will give lectures at the Cohasset Center for Student Research, an institute dedicated to involving high school students in marine research just south of UMB.

Synergies with other projects: The data from the removal experiment for H3 conforms to the protocols for the global Kelp Ecosystem Ecology Network experiment (http://kelpecosystems.org). This project seeks to have PIs from around the world replicate a kelp removal experiment to look at biogeographic variation in responses to removal. The wave-protected sites in H3 would provide data for this larger global effort. Records of kelp abundances from control plots will also be shared with the Northeastern Regional Association of Coastal Ocean Observing Systems Sentinel Monitoring Program, of which I am a member. Last, this proposal complements a submitted MIT SeaGrant proposal that aims to develop an inexpensive open source wave-height sensor to examine wave impacts on kelp removal. If both are funded, plots in H4 will have wave heights measured directly at the site scale.

H. Project Timeline & Logistics

Logistics: I have pre-existing relationships with both the Shoals Marine Laboratory (SML) and Salem State's Cat Cover Marine Lab (CCML). Both have boats and access to dive facilities (either nearby shops or facilities at the lab) that enable easy access to field sites. During the winter, if Salem State's Boat is not available, several other boat options are available. Work will be facilitated by my technician Ted Lyman, a trained Dive Safety Officer who worked with me in gathering the preliminary observations. Lyman has an extensive knowledge of diving and subtidal research techniques.

Timeline: I will sample sites at SML and Salem Sound for H1 in the summer of year 1-2. In year 3, I will sample sites for H1 only in Salem Sound. In summer if year 1, I will initiate experiments for H2 at SML and CCML. I will resample these sites in late summer. During the fall I will setup experiments for H3 and begin recruit sampling for H4. Recruit sampling will occur monthly, or as sea conditions permit. In year 2, plots for H2 and H3 will be resampled. Recruitment collection will continue. In the fall of year 2, I will initiate a second round of experiments for H3 and H4.

	Year 1			**Year 2**			**Year 3**		
	Summer	Fall	Winter & Spring	Summer	Fall	Winter & Spring	Summer	Fall	Winter & Spring
Sampling for H1	x			x			x		
Removals for H2	x								
Resampling H2	x			x					
Removals for H3 & H4		x			x				
Resampling for H3 & H4			x	x		x	x		
Recruitment Panels for H3		x		x					
Recruit Samples for H4		x	x	x	x	x	x	x	
Analysis					x			x	x
Write-Up						x			x
Present H1 & H2 at Meetings					x	x			
Present H3-H4 at Meetings								x	x

Feasibility: Based on work I have already completed performing surveys around Appledore and Salem State, initiating one round of one experiment should take ~ 1-2 weeks of dives (conditions and number of available divers depending). Re-surveying should be even more brief. SML's facilities enable easy access to the water so that this work should be done swiftly. Similarly, my lab uses CCML as a base for most of our local field operations, and have found that access is similarly straightforward, if slightly reduced due to not being residents at the lab. Year-round recruitment sampling will prove more difficult, hence the reduced number of sites for H4. Once gear is installed, it should take 1-2 days to replace recruitment panels per month.

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Jarrett E. K. Byrnes

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Professional Preparation & Appointments

2012 – Present Assistant Professor, University of Masachusetts Boston
2010 - 2012 Postdoctoral Fellow, National Center for Ecological Analysis and Synthesis
2008 - 2010 Postdoctoral Fellow, Santa Barbara Long Term Ecological Research Project
2002-2008, UC Davis, Population Biology, M.S. 2003, Ph.D. 2008
1997-2001 Brown University, Bachelor of Science in Biology.

List of Five Relevant Products

1. Byrnes J.E., Johnson L.E., Connell S.D. et al. (2013) The sea urchin – the ultimate herbivore and biogeographic variability in its ability to deforest kelp ecosystems. PeerJ PrePrints, 1, e174v1. [doi]

2. Byrnes, J.E.K., Cardinale, B.J., and Reed, D.R. 2013. Sea urchin grazing increases with prey diversity on temperate rocky reefs. *Ecology*. 94:1636-1646. [doi]

3. Byrnes, J.E., Reed, D.C., Cardinale, B.J., Cavanaugh, K.C., Holbrook, S.J., and Schmitt, R.J. 2011. Climate driven increases in storm frequency simplify kelp forest food webs. *Global Change Biology*. 17: 2513-2524. [doi]

4. Byrnes, J.E. and Stachowicz, J.J. 2009. The consequences of consumer diversity loss: different answers from different designs. *Ecology*. 90: 2879-2888. [doi]

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List of Five Other Products

1. Byrnes, J. E. K., L. Gamfeldt, F. Isbell, J. S. Lefcheck, J. N. Griffin, A. Hector, B. J. Cardinale, D. U. Hooper, L. E. Dee, and J. E. Duffy. In Press. Investigating the relationship between biodiversity and ecosystem multifunctionality: Challenges and solutions. *Methods in Ecology and Evolution* [doi][R package]

2. O'Connor, M.I. and **Byrnes, J. E.K.** Biodiversity and Ecosystem Function in Marine Ecosystems. 2013. In *Marine Community Ecology and Conservation*, M. Bertness, J. Stachowicz, and B. Silliman, eds. Sinauer. Sunderland, MA

3. Hooper, D.U., Adair, E.C., Cardinale, B.J., **Byrnes, J.E.K.**, Hungate, B.A., Matulich, K.L., Gonzalez, A., Duffy, J.E., Gamfeldt, L., O'Connor, M.I. 2012. Biodiversity loss ranks as a major driver of ecosystem change. *Nature*. 286: 105-108. [doi]

4. Byrnes, J.E. and Stachowicz, J.J. 2009. Short and Long Term consequences of increases in exotic species richness on water filtration by marine invertebrates. *Ecology Letters*. 8: 830-841. [doi]

5. Byrnes, J.E., Reynolds, P.L., Stachowicz, J.J. 2007. Invasions and extinctions reshape coastal marine food webs. *PLoS One*. 2: e295. [doi]

Synergistic Activities

1. Global Impacts of Climate Change on Kelp Forests. Leader, National Center for Ecological Analysis and Synthesis working group.

2. The future of publishing in ecology, evolution, and environmental sciences. Leader, National Center for Ecological Analysis and Synthesis working group.

3. Author of I'm a chordata! Urochordata! http://www.imachordata.com/. A science blog discussing ecology, marine biology, and the culture of science in the modern age.

4. Contributing Developer for Lavaan - Analysis of latent variable Structural Equation Models in R. http://lavaan.org

5. Co-Creator of The #SciFund Challenge. A large-scale effort for scientists to teach outreach to scientists by getting them to crowdfund their research. $252K raised to date http://scifundchallenge.org

6. Participant in Biodiversity and the functioning of ecosystems: translating results from model experiments to functional reality. National Center for Ecological Analysis and Synthesis working group.

7. Participant in Dissertation Initiative for the advancement of Climate Change ReSearch (DISCCRS) participant. Interdisciplinary workshop in climate change communication.

Collaborators and Co-Authors: Balvanera, Patricia, UNAM; Cavanaugh, Kyle, Smithsonian Environmental Research Center; Duffy, J. Emmett, Virginia Institute of Marine Sciences; Edwards, Kyle, University of Michigan; Gamfeldt, Lars, University of Gothenburg, Sweden; Gonzalez, Andrew, McGill University; Holbrook, Sally, University of California Santa Barbara; Hooper, David, Western Washington University; Isbell, Forest, University of Minnesota; O'Connor, Mary, University of British Columbia; Reynolds, Pamela, Virginia Institute of Marine Sciences; Schmitt, Russ, University of California Santa Barbara, Hughes, A. Randall, Northeastern University; Kimbro, David, Northeastern University

Graduate Advisors and Postdoctoral Sponsors: Bradley J. Cardinale, University of Michigan. Daniel C. Reed, UC Santa Barbara.

Thesis Advisor: John J. Stachowicz, UC Davis.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION University of Massachusetts Boston	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jarrett Byrnes	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jarrett Byrnes - PI	0.00	0.00	1.00	7,992	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	7,992	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	39,591	
3. (1) GRADUATE STUDENTS				20,000	
4. (2) UNDERGRADUATE STUDENTS				12,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				79,583	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				12,297	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				91,880	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				6,824	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				6,375	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				10,300	
TOTAL OTHER DIRECT COSTS				16,675	
H. TOTAL DIRECT COSTS (A THROUGH G)				115,379	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 52.5000, Base: 115379)					
TOTAL INDIRECT COSTS (F&A)				60,574	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				175,953	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				175,953	

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $
PI/PD NAME Jarrett Byrnes	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. NAME*	Date Checked / Date Of Rate Sheet / Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Massachusetts Boston			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jarrett Byrnes			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jarrett Byrnes - PI	0.00	0.00	1.00	8,232	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	8,232	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	40,779	
3. (1) GRADUATE STUDENTS				20,000	
4. (2) UNDERGRADUATE STUDENTS				12,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				81,011	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				12,634	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				93,645	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,424	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,825	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				3,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				10,300	
TOTAL OTHER DIRECT COSTS				18,125	
H. TOTAL DIRECT COSTS (A THROUGH G)				120,194	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 52.5000, Base: 120194)					
TOTAL INDIRECT COSTS (F&A)				63,102	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				183,296	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				183,296	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME Jarrett Byrnes	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **University of Massachusetts Boston**	FOR NSF USE ONLY			
	PROPOSAL NO.	DURATION (months)		
		Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Jarrett Byrnes**	AWARD NO.			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Jarrett Byrnes - PI**	0.00	0.00	1.00	8,479	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	8,479	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	42,002	
3. (1) GRADUATE STUDENTS				20,000	
4. (2) UNDERGRADUATE STUDENTS				12,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				82,481	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				12,981	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				95,462	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,424	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				4,305	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				3,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				4,300	
TOTAL OTHER DIRECT COSTS				11,605	
H. TOTAL DIRECT COSTS (A THROUGH G)				115,491	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 52.5000, Base: 115491)**					
TOTAL INDIRECT COSTS (F&A)				60,633	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				176,124	
K. RESIDUAL FUNDS				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				176,124	

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Jarrett Byrnes**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Massachusetts Boston**						
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Jarrett Byrnes**						

FOR NSF USE ONLY

PROPOSAL NO.	DURATION (months) Proposed	Granted
AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Jarrett Byrnes - PI**	0.00	0.00	3.00	**24,703**	
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	3.00	**24,703**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**3**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	36.00	0.00	0.00	**122,372**	
3. (**3**) GRADUATE STUDENTS				**60,000**	
4. (**6**) UNDERGRADUATE STUDENTS				**36,000**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**243,075**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**37,912**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**280,987**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				**23,672**	
2. FOREIGN				**0**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**15,505**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**6,000**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**0**	
5. SUBAWARDS				**0**	
6. OTHER				**24,900**	
TOTAL OTHER DIRECT COSTS				**46,405**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**351,064**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				**184,309**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**535,373**	
K. RESIDUAL FUNDS				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**535,373**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME	FOR NSF USE ONLY		
Jarrett Byrnes	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget and Justification

A. Senior Personnel: We one month of summer support for the PI. This will enable the PI to conduct summer experiments and supervise the undergraduates at the start of the field season.

	Year 1	Year 2	Year 3
PI	7,992.00	8,232.00	8,479.00
Technician	39,591.00	40,799.00	42,002.37
Graduate Student	20,000.00	20000.00	20,000.00
Undergraduate	12,000	12,000	12,000

B. Other Personnel: We request support for a research technician Ted Lyman for three years ($39,591 in year 1, $40,779 in year 2, and $42,002.37 based on current university salary). He has worked at the Byrnes lab manager for one year, and before was the Dive Safety Officer at Northeastern University's Marine Science Center, and is currently assisting PI Byrnes in developing a dive safety program here at UMB. He also has a background in IT support at biomedical startups. This technician position will encompass several duties: 1) assisting in conducting the experiments at SML and CCML, 2) preparing and deploying flow blocks, 3) monthly recruitment sampling, 4) management of project data. Additionally, given his background, Lyman will help keep the project participants up to date on all relevant certifications and oversee new undergraduate researchers along with PI Byrnes.

We request support for a graduate student for the three years of the grant for one academic semester and summer support each year. The graduate student will assist in the removal experiments and recruitment sampling. The graduate student will use the unsampled areas of the clearance plots as a potential site to conduct additional experiments related to the project.

Two Undergraduate personnel to assist in summer manipulations, surveys, and independent research will be paid a summer stipend of $6,000/each for a total of $12,000 per year.

C. Fringe: 1.73% rate applies to PI for summer compensation. 27.99% applies to the benefited technician and 1.42% applies to the Graduate undergraduate students stipend in the summer only. Fringe Rate is negotiated between DHHS and the Commonwealth of Massachusetts. Fringe rates includes: General Fringe, Health & Welfare, Medicare, Unemployment Insurance, Universal Health Insurance and Worker's Compensation Insurance.

D. Equipment: n/a

E. Travel – Domestic Travel:
SML: During years one and two, we will require travel to and from the Shoals Marine Lab ($66 ferry trip/person and $50 for gas and tolls = $314/year) and lodging for 14 days for 1 faculty, 1 tech, and 2 students ($6510). Total travel to SML per year $6824.

Travel is also requested for PI and 1 graduate student to travel to the Benthic Ecology Meeting in years 2 & 3. Roundtrip airfare $250/per person; Registration PI $250 and graduate student $150; 3 nights hotel $175 per night; 2 Taxi rides $40 per ride and per diem $45/day for 2 days. Total travel for meetings is $1600 per year for two years.

F. Participant Support Cost: N/A

G. Other direct costs:

Supplies: In year 1 only, we request $300 for the purchase of gypsum dental cement for flow blocks. We request an addition $50 for hardware cloth and $50 for caulking to attach the blocks for field deployment. We request $50 for cable ties both for attaching gear to site markers, but also for quick gear repairs, to attach site ID tags, and other subtidal uses. In years 1-2 we request 100 each for 200' of ½" rebar as site markers, and $420/year for marine epoxy (A-788 Splash Zone Compound, aka Z-Spar) to attach any marine hardware or site markers. Last, we request $2600/year for 400 tank fills (100 dives/year for 4 divers) every year at $6.50/fill. Dropbox file sharing subscription $1080 per year for three years; 5 48"x96" dark grey ¼" acrylic sheets at $125/sheet total $625 per year in years 1 & 2; 20 Onset pendant temperature loggers @$64/each in year 1 only total $1280.

Total supplies requested in Year 1: $6375; Year 2; $4825 and Year 3 $4305

Equipment Repair and Leasing: During the work in CCML out of Salem Sound, we will need to rent boat time, service our gear, and fill tanks at Undersea Divers, Inc. The costs are as follows on an annual basis:

Item	Cost per Year
Annual Gear Service for 5 full sets of gear ($300/set)	1,500.00
Misc Field Gear Replacements Annually	500.00
Boat Fees at Salem State for 50 days at $100/day (Year 1 & 2)	5,000.00
Boat Fees at Salem State for 20 days at $100/day (Year 3)	2,600.00
Gas for Salem State Boat	300.00
Winter Boat Rental for 10 Days at $300/Day	3,000.00

Publication: We also include $3,000 during years 2 and 3 Open Access publication costs.

H. Indirect Rate is 52.5%: F&A Rate of 52.5% is negotiated between DHHS and the University of Massachusetts Boston.

Current and Pending Support

(See GPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Jarrett Byrnes

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Drivers and Passengers of Shifts in Benthic Foundation Species Dominance

Source of Support: NSF

Total Award Amount: $ 535,373 Total Award Period Covered: 07/01/14 - 06/30/17

Location of Project: Boston, MA

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Preliminary Proposal: Multi-stressor impacts on saltmarsh persistence

Source of Support: NSF

Total Award Amount: $ 0 Total Award Period Covered: 08/01/14 - 07/31/15

Location of Project: Boston, MA

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.00

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: FOod Web Structuer as a Driver of Mulitple Ecosystem Functions in New England Salt Marsh Ecosystems

Source of Support: MIT SeaGrant

Total Award Amount: $ 165,536 Total Award Period Covered: 02/01/14 - 01/31/16

Location of Project: Boston, MA

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment and Other Resources

UMB Laboratory: On the UMB campus, students will be placed in the PI's fully equipped research laboratory in the Biology Department. The 600 sq. ft. lab is fully supplied with computers, a fume hood for sample processing, and sample freezer, a full range of shop tools, dissecting scopes, and other equipment for lab work. A new building, the Integrated Sciences Complex, where the PI and lab will move, is scheduled to open in May 2014.

UMB Computer: UMass Boston has extensive computer resources for this project. Each research lab has an array of internet- connected Macs and PCs. UMB has 10 computer labs with over 250 PCs and printers available for student use, as well as specialty computer facilities and computer teaching laboratories. The PI will provide computer facilities in his lab for student work.

UMB Office Support: The Program Coordinator has dedicated office space with computer equipment as well as access to a full array of support equipment such as copy and fax machines. The Directors and all participating faculty have appropriate office space. The offices of the Biology Department and the Dean of the College of Science and Mathematics have staff and supplies that support this project and our shipping needs.

UMB Field Equipment: PI Byrnes's lab is currently equipped with the necessary equipment for a subtidal research program: wet and dry suits for lab personnel, full sets of dive gear - including BCDs, regulators, mask, fins, and weights – and a full suite of field sampling gear (PVC quadrats, transect tapes, etc). The lab also has several underwater digital still and video cameras for sampling sites and recording identifying photographs of organisms. PI Byrnes is currently in the process of purchasing a 20' marine skiff with trailer and vehicle.

Cat Cove Marine Lab: For Sampling in Salem Sound, PI Byrnes will work out of Salem State's Cat Cover Marine Lab. CCML provides a 20' skiff with easy access to the islands in Salem Sound and flowing seawater tables.

Shoals Marine Lab: For sampling at SML, PI Byrnes, Grabowski, Dijkstra, and subawardee Witman will work from UNH and Cornell's Shoals Marine Lab. SML provides multiple inflatable boats with access to the entire archipelago. Additionally, the larger R/V Heiser and Kingsbury can be used to access more difficult sites or carry large numbers of divers. SML provides housing accommodations and board for all scientists. It also provides tank fills and facilities for equipment storage and maintenance.

Data Management Plan

1. Types of data

Data from experiments will be collected by divers on SCUBA. Data will consist of quadrat and point count data of species abundances from. In general, data sheet formats will include identifying information for individual quadrat or transect, taxon name being sampled, and the abundance recorded of the relevant taxon. Units of data (% or count) will be set by sampling method and taxon and unique to each survey. All data sheets will be scanned and archived. Data entry will be performed using scanned data. If scans are illegible, the original data sheets will be located and rescanned so that they are legible. Data will be Quality Assured by interns reading back data from sheets to check for consistency. Data will be spot checked by lab technicians as a final QA step.

Location of each numbered recruitment panel will be recorded upon deploymen.t Data from recruitment panels will be recorded in the lab on data sheets recording panel number and number of kelp recruits. Data will be archived and entered as above.

We will also keep a field log of all geospatial information of plot locations for future resurveys and for meta-data purposes.

The final data will comprise a collection of comma separated files that will include entries for part of the project, site, project name, measurement type, and measurement value. R scripts used to create derived data sets for analysis will be archived separately and have their workflows documented. Derived data files will be stored in a separate directory from the original data. Further R scripts for analyses will be archived separately from data processing scripts.

2. Data and metadata standards

All data files will have metadata stored in accompanying text files. Text files will fully document the spatial and temporal information regarding each data set. Text files will include a full description of the methodology used to collect data, and a description of the measurements contained in each column. A second meta-data table will the full taxonomy of each taxon sampled in the data as well as a brief description and references to Encyclopedia of Life ID numbers. All data will be permanently archived using Morpho at KNB (see below) to facilitate the creation of meta-data conforming to the EML standard.

Analysis scripts will be commented extensively, and the workflow for each analysis will be documented in an accompanying text file.

3. Policies for access and sharing

All derived and raw data will be made publicly available via the Knowledge Network for Biocomoplexity (KNB). The PI has previously participated in depositing data sets at KNB while a postdoctoral fellow at NCEAS. All metadata will be supplied with data sets, as will scripts for creating derived data sets. Scripts for analysis will be made public as appendices to published papers.   When possible, data will also accompany published paper as appendices (e.g., for PLoS One). Data will be fully open access with the only requirement being citation to the data product.

Data from the fall experiments will also be deposited with the Kelp Ecosystem Ecology Network for use with their growing data archive of kelp removal experiments.

4. Policies and provisions for re-use, re-distribution

Experimental data will be made available upon publication of the first paper using the data with the requirement that the data product and paper be properly cited. While future authors will be encouraged to contact the PI and co-authors with questions about the data, no requirements or restrictions will be placed on the use of the data.

5. Plans for archiving and preservation of access

Short-term

In the short-term, data and scripts will be stored on laboratory Macintosh computers and backed up nightly to a hard drive. Additionally, the lab will use the Dropbox service (https://www.dropbox.com/) to persistently backup the data as it is entered.

Long-term

Long-term archiving will be via KNB as described in the policies for access and sharing. If KNB should fail, we will move data to another member node of the Data One project to ensure that it is fully searchable and accessible to the general public.