NRT-DESE: Risk and uncertainty quantification in marine science and policy

PROJECT DESCRIPTION

I. List of core participants

Name	Role	Affiliation	Discipline	Training Grants
Lorenzo Ciannelli	PI	CEOAS	Fisheries Oceanography	NSF RCN-SEES
Julia Jones	Co-PI	CEOAS	Geography	NSF IGERT
Michael Banks	Core member	FW	Genetic, genomics	Program director
Alix Gitelman	Co-PI	COS	Statistics	NSF IGERT
Enrique Thomann	Core member	Mathematics	Probability and stochastic modeling	NSF IGERT
Juan Restrepo	Co-PI	Mathematics	Uncertainty Quantification	NSF IGERT
Sinisa Todorovic	Co-PI	EECS	Computer science	N/A
Flaxen Conway	Core member	Liberal Arts	Social science	Program director
Alexander Kurapov	Core member	CEOAS	Ocean modeling	N/A
Cynthia Char	EE	Char Assoc.	Human Development	NSF DRK12 &AISL

CEAOS: *College of Earth, Ocean, and Atmospheric Sciences*; EECS: *Electrical Engineering and Computer Science*; COS: *College of Science*; FW: Fisheries and Wildlife; EE: external evaluator. The PI and all co-PIs' institutional affiliation is the Oregon State University (OSU).

II. Theme, vision, and goals

We propose to train a new generation of leaders who can combine mathematics, statistics, and computer science with environmental and social sciences to study and manage ocean systems.

The ocean is the last great frontier on Earth, a major driver of climate and productivity, and a critical resource for humans and wildlife. Coastal marine ecosystems of the U.S. West Coast in particular are highly productive, with abundant and diverse species assemblages. Environmental change and human actions continually alter these ecosystem services. Data-enabled science and engineering (DESE) are transforming our ability to understand and manage environmental changes to ocean systems. New ocean observatory platforms and analytic approaches are identifying drivers of change that were unknown even a few decades ago, such as global warming, acidification, and expansion of hypoxic regions. New technologies and genomic data reveal how policy and management strategies produce unintended consequences, such as fisheries-induced evolution. Because of these scientific and technological transitions, marine sciences will be a major venue for computational and DESE research, and for development of cross-disciplinary educational models that are vital to training STEM graduate students and fostering engagement with stakeholders. **We envision a future in which scientists and managers work seamlessly using large and ever-expanding data resources, to understand the top-down effects of human actions and the bottom-up effects of climate-change on the ocean system**. **These collaborations will have as a fundamental component quantification**

and communication of the risks and uncertainties that are inherent in model forecasts and policy actions, and the ultimate goal of devising management solutions in the face of these changes and uncertainties.

We propose to achieve these goals (Fig. 1):

Goal 1: Educate and train scientists, engineers, and resource managers to work in transdisciplinary teams that create tools and techniques for DESE.

Goal 2: Promote a transformative and scalable new marine science and policy education program that teaches students to quantify and communicate risk and uncertainty.

Goal 3: Discover mechanisms that control the response of marine systems to climate change and human pressures.

Goal 4: Develop and apply evidence-based practices for recruiting, training, and retaining students and for placing them into successful careers, with an emphasis on underrepresented minorities in STEM

Goal 5: Evaluate and disseminate our programmatic elements for conducting transdisciplinary research and education and for broadening participation of underrepresented minorities in STEM.

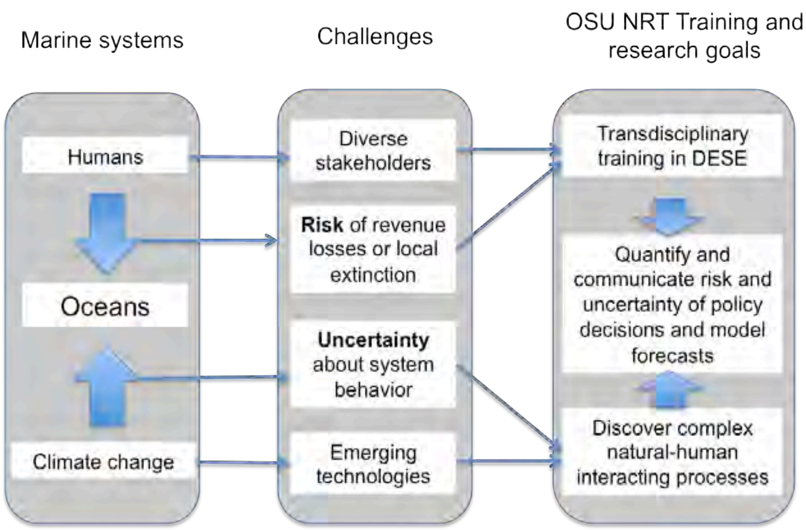

Figure 1. The OSU NSF Research Traineeship program in Data-Enabled Science and Engineering (DESE) addresses the challenges of risk and uncertainty in marine systems that emerge from top-down policy driven by diverse stakeholders and bottom-up changes driven by climate change. The training and research goals of the program are to promote transdisciplinary professional and technical training in DESE of natural and social scientists, to discover complex natural-human interacting processes, and to quantify and communicate risk and uncertainty of policy decisions and of model forecast.

II.A Need for trained professionals

Current models for educating doctoral- and master-level marine scientists and managers do not address the new workplace requirements of marine science professionals (Langholz and Abeles, 2014). The call for integrated and participatory approaches to studying and managing ocean resources (e.g., Armitage, 2009) recognizes that marine resource management requires information not only about organisms and their environments but also the social, cultural, and historical factors that motivate human actions (Berkes, 2011). Professionals in marine science must cross disciplinary boundaries to address resource management problems (Paterson et al., 2010). Complex marine resource management issues need solutions that bridge the natural, technological, and social sciences. Scientists and managers need to work in integrated teams to generate new scientific knowledge and to develop new policies for natural resource governance.

II.B Graduate training needs

Students indicate that mentoring, financial support and a sense of belonging to the program are key elements leading to successful retention and graduation in STEM fields. At the same time, current approaches to STEM graduate education fail in several key respects (CGSETS 2010, 2012). These approaches do not provide students with sufficient ties to the workplace and to stakeholders in general. They do not teach students the skills to communicate scientific research, especially uncertainty and risk, to a diverse audience. They do not teach the professional skills required to work in a team of cross-disciplinary experts. They do not teach students the administrative skills that would enable future professionals to manage and inspire people they supervise (Blickley et al. 2012).

II.C New training approaches

We propose to implement and disseminate a new, scalable and potentially transformative educational model in which transdisciplinary research teams (Rosenfield, 1992) apply state-of-the-art DESE techniques to solve real-world problems in marine science (NRC, 2014). We will train teams of students, connect them with internships in science and policy, and then guide those teams to conduct joint research. Students with diverse expertise will leverage each other's strong disciplinary knowledge and skills as they collaborate to address complex stakeholder-identified climate and policy problems (Ciannelli *et al.*, 2014). The barriers that separate the STEM disciplines required for DESE will dissolve as the participants develop a shared language and a shared conceptual framework. Students will engage with stakeholders from industry, government agencies, and non-governmental organizations (NGOs), thereby gaining direct experience of the tensions and conflict resolutions inherent in resource management, as well as direct exposure to diverse career pathways. They will learn to quantify and communicate the risk and uncertainty inherent in policy decisions and model forecasts. They will develop proficiency in transferable professional skills, including communication, administration, and collaboration.

II.D Integration of Research and Training Elements

DESE in marine science involves moving from data to information, then to knowledge, then to action. We rely on signal processing and data interpretation techniques to extract scientifically meaningful information from petabytes of raw data from sensor networks and environmental monitoring protocols. To develop knowledge, we test our observations against theory by building models and fitting multiple streams of interpreted data. To connect science with policy and management, we communicate the forecasts of our models with appropriate perspectives on risk and uncertainty. Considerations of risk and uncertainty grow in importance in a big data world, where the potential of false findings grows with the sample size (Spiegelhalter 2014). The theoretical principles, modeling tools, computational techniques, and engineering expertise for developing and implementing DESE in marine science reside within computer science, oceanography, geography, mathematics, statistics, and social sciences. Academia lacks cross-disciplinary research and education programs to train a new generation of scientists to integrate these principles, tools, and techniques. Such research training is a current national need. Our research and education program will satisfy this need.

II.E Potential to enhance current degree programs and methods of graduate training at the host institution

The newly launched Oregon State University (OSU) Marine Science Initiative (MSI) will weave together the natural and social sciences in an exceptional education, research and outreach program. The MSI will explore all facets of the marine environment and its dynamic connection to mankind while promoting the economic and social progress of coastal communities. The OSU

NRT project will complement and enrich MSI research and education programs while broadening participation of under-represented minorities in STEM. Formal links between the NRT, Graduate School, and the MSI will ensure that best practices for transdisciplinary education implemented in our program will benefit the larger OSU community (i.e., PI **Ciannelli** and core member **Conway** serve on MSI Curriculum Committee and OSU Graduate School service on External Advisory Team for the NRT [see Section VI]). The OSU Graduate School, MSI, and the Deans from our four Colleges have expressed interest and commitment to OSU NRT program goals.

II.F Synergy, dissemination, and scalability

Our proposed NRT program links students and faculty across four colleges (Science; Earth, Ocean and Atmospheric Sciences; Liberal Arts, and Engineering) and complements Oregon State University's strong commitment to cross-disciplinary education, particularly in marine science. The Graduate School at OSU supports and oversees ten cross-disciplinary degree, certificate, or minor graduate programs (please see Institutional Support Letter from OSU Graduate School). Further, the Graduate School at OSU has embarked on a comprehensive initiative—Holistic Graduate Education—to provide graduate students with professional development opportunities, including orientation, responsible research, diversity awareness, issues in higher education, and research innovation and commercialization. A planned new space for the Graduate School will be designed to promote cross-disciplinary graduate training and to promote involvement with stakeholders outside the university (including future employers). The OSU NRT will benefit from and contribute best practices in transdisciplinary education to all these programs, as we find innovative solutions to the complex technological challenges arising from data-enabled science.

We propose to disseminate NRT curricula, best practices, and evaluations to wider academic communities by publishing our discoveries in peer-reviewed educational journals. In addition, the co-PIs will present the project goals and programmatic elements at professional meetings and workshops (e.g., Ocean Science, Ecological Society of America). We propose to develop a transcript-visible graduate minor in Risk and Uncertainty Quantification and Communication to document student achievement in the NRT. Our novel educational model has the potential to improve the effectiveness of environmental science programs at many universities by helping them to integrate data-enabled science and engineering into their curricula.

II.G Broadening participation

This NRT will aim to increase the number of graduate students from under-represented minorities (URM) in STEM disciplines. We will aim for >50% participation by Hispanics, African Americans, American Indians/Alaska natives (in all disciplines), as well as women (in computer science, statistics, and mathematics). To align our program with Oregon demographics, we will also target other groups who are under-represented in the nation's science and engineering enterprise: students from low-income families, rurally isolated students, first-generation college students, veterans, and single parents. We have structured our program around four objectives for broadening participation, which we will describe in more detail in Section VII:

Objective 1: Inspire and recruit URM students for graduate studies in marine science and policy
Objective 2: Increase admissions of URM students to graduate programs in NRT-DESE
Objective 3: Retain URM students to completion of MS or PhD in NRT-DESE
Objective 4: Place URM graduates in careers relevant to their NRT-DESE training

III. Education and training

The educational and training component of our program addresses the first and second goals of the OSU NRT, namely: 1) *Educate and train scientists, engineers, and resource managers to work in transdisciplinary teams that create tools and techniques for DESE,* and 2) *promote a transformative and scalable new marine science and policy education program that teaches students to quantify and communicate risk and uncertainty*.

The learning outcomes for our proposed NRT program will train students to:

1. interpret data from multiple sources, calculate risk and uncertainty, and construct analyses of marine systems
2. combine concepts from social and natural science and compose collaborative analyses addressing humans and climate change effects on marine systems,
3. assess needs, perceptions, and roles of stakeholders, and explain risk and uncertainty to stakeholders in industry, policy, non-governmental organizations
4. achieve professional skills, including communication, administration, and personnel management.

While pursuing these learning objectives, students will obtain a **minor** in Risk and Uncertainty Quantification and Communication.

III.A Proposed Traineeship Model

Table 1. How training elements support learning outcomes in NRT-DESE in marine systems. Numbered learning outcomes are listed in the previous paragraph.

Training element	Learning outcome			
	1	2	3	4
1. Boot camp (*)		■	■	
2. Technical coursework (*)	■			
3. Training on work group function (*)			■	■
4. Internship		■		■
5. Communication workshop (*)			■	
6. Group project	■	■		
7. Thesis chapter	■		■	
8. Peer mentoring seminar (*)				■
(*) Part of the new OSU minor in Risk and Uncertainty				

To achieve the learning outcome of the NRT program, each student cohort will follow a training path consisting of: 1. Boot camp: group visits to field sites and interactions with stakeholders; 2. targeted coursework in risk and uncertainty quantification; 3. training on work group structure; 4. internship; 5. workshop on communication skills; 6. group project; 7. thesis chapter; 8. peer mentoring colloquium (Table 1).

(1) **Boot camp**. Prior to the start of the fall quarter, each new cohort of NRT trainees will participate in a week-long residential “boot camp” based at OSU’s Hatfield Marine Science Center (HMSC) in Newport, (http://hmsc.oregonstate.edu/). During the week-long boot camp, faculty and guest speakers from industry, government agencies and NGOs will present and discuss their research programs, and in informal evening sessions, will illustrate how cross-disciplinary collaboration has enriched their careers and promoted discovery in their disciplines. Students from previous NRT cohorts will also be invited to share their progress and experiences in the program. Through site visits to local shorelines, research vessels, fishing boats, resource management agencies, and seafood processors, incoming NRT trainees will have an opportunity to experience first hand the diversity of research topics and professional challenges related to the study and management of marine renewable resources. The HMSC is equipped with the necessary facilities to host large groups of scientists and students (e.g., dorms, auditorium, classrooms); it is proximal to OSU and NOAA ship facilities, ocean observatories headquarters, and stakeholder organizations; and it is uniquely positioned to expose students to the reality of aquatic and marine data-enabled science and engineering. The NRT Executive Team will organize the boot camp (see Section VII).

(2) **Targeted coursework**. Students will pursue targeted course work on risk and uncertainty quantification and on analysis of big data (Table 2). Students will learn long-standing approaches in decision theory, stochastic optimization, ruin theory, large deviations, and modern methods of uncertainty quantification in a model free setting. Important pedagogical resources in these areas date back to Bernoulli’s introduction of utility and von Neumann-Morgenstern’s ideas on decision theory and game theory, to Cramer’s calculations of ruin probabilities and large deviation for insurance, to new model free approaches involving computer simulations and

qualitative estimation methods based on qualitative properties, e.g., convexity and inequalities (e.g., Owhadi et al., 2013). A new cross-disciplinary text on risk and uncertainty by Kluppelberg et al. (2014) and an existing course on Actuarial Mathematics (Math 567, Waymire and Thomann) provide pedagogical resources aimed at students from diverse backgrounds authored by researchers at the forefront of this area. Co-PI **Juan Restrepo**, and core member **Enrique Thomann** will deliver this course (Table 2).

The big data component will train students to address challenges and master techniques to analyze large volumes of data. Statistics provides foundational support for these activities, from helping to pose researchable questions, to collecting data using probability sampling, to making decisions using existing or new statistical methods, to generalizing results beyond the data in hand. Specifically, training will explore questions in data-enabled science to derive information and knowledge from massive datasets on environmental factors (e.g., bio-physical properties of ocean, genomic information) and human activity (e.g., economic, political, ethical perceptions and behavior affecting ocean systems). These questions include: (1) How much data are necessary for answering important questions? (2) What are the tradeoffs between improved resolution in time or space versus broader temporal and/or spatial coverage? (3) What are the appropriate spatial and temporal scales for sampling key ecological and social processes? Co-PIs **Alix Gitelman** and **Sinisa Todorovic** will offer these courses (Table 2).

Table 2. New graduate minor in "Risk and Uncertainty". This minor will be open to all OSU students, and will be particularly instrumental for the newly launched MSI curricular program.

Courses in graduate minor	Credits
OC 5XX Boot camp: Marine systems and stakeholders (**Ciannelli**)	3
MTH 567 Actuarial mathematics (**Thomann, Restrepo**)	3
ST 599 Modern statistical methods - large datasets (**Gitelman**), or CS555 Signal and image processing (**Todorovic**), or CS 599 Big data analysis and estimation (**Todorovic**)	3 4 4
GEOG 5XX Spatial models of geographic hazards (**Jones**), or OC 440 Biological Oceanography (**Ciannelli**)	3 4
GEOG 5XX Work group function (**Jones**)	2
SOC 5XX Communication workshop (**Conway**), or COMM 524 Communication in organization: theories and issues	2 3
OC 507 Peer mentoring seminar	1
Total	18

(3) **Professional training on cost and benefits of collaborative working structure**. This training element provides trainees with a comprehensive view of how work groups function. The course will cover organizational structures of various professional settings (including academia), large and small business enterprises, NGOs, and government institutions. Akin to the ecological theories linking structure and functions in biological communities, students will learn how the structures of various work groups influence their collaborative work outcome, and thus understand the cost and rewards associated with different organizational and collaborative groups. Training will also expand on the metrics to quantify collaborative success, both at the individual and team level (e.g., Goring et al., 2014), which will be used to weigh the outcome of the collaborative NRT training elements (i.e., group projects and thesis chapters). Training will build on existing research of co-PI **Julia Jones** at OSU that applies visual analytics to understand work group diversity and function and to quantify its success (Pham et al., 2014a,b). Students (and faculty) will become familiar with a variety of professional settings, gain understanding of career paths that best fulfill their aspirations, and learn how their work can better fit the needs of various types of organizations. Co-PI **Jones** will teach this course (Table 2). We anticipate involving colleagues from the OSU College of Business for the financial and entrepreneurship portion of this module.

(4) **Internship**. All NRT trainees will be required to take one or two terms of internship. Trainees will choose either a *science* or *policy* oriented internship, emphasizing DESE training or communication and policy, respectively. Internships will be assigned based on the trainee's stated interests and professional aspirations assessed through the Individual Development Plan (IDP, see sect III.B). Prior to embarking in the internship, each student and internship host will define goals and deliverables. The Internship Team (see Sect VI) will assign internships consistent with the research path that student clusters will follow for their collaborative project and thesis chapter. Well-designed internships are also a springboard for new career opportunities, because students begin to develop a professional network, and gain their first post-PhD employment (typically as a post-doc). Through our network of collaborations we have already obtained institutional commitment for our internships program from NOAA, fishermen associations (Albacore tuna commission), and the Center for Doctoral Training (CDT) at the University of Liverpool (please see attached letters of support). The CDT operates in the Institute of Risk and Uncertainty maintaining close links with industry, government and NGO's (http://www.liv.ac.uk/risk-and-uncertainty/postgraduate/cdt_risk/). Trainees who choose to work with the CDT will receive a global perspective on stakeholder engagement and user-inspired research. We are also open to and will seek new internship opportunities (e.g., NGOs) as the NRT program develops.

(5) **Communication workshop**. Our NRT trainees will learn to communicate risk and uncertainty of natural hazards, model forecasts, and policy decisions. Perceptions of risk vary among individuals, social groups, and institutions in marine science and policy, and these perceptions influence behavior through choices, policies, and structures (Berns and Conway, 2012). For example, fishermen face risks of revenue loss, resource depletion, and weather events, while they struggle to respond to natural hazards (e.g., hypoxia, ocean acidification, drought) and the increasingly startling, yet uncertain, predictions of how much worse their problems may become. Scientists are familiar with risks and uncertainty associated with natural events and human actions, but they struggle to understand the risks (intended and unintended) associated with different policy actions. Decision and policy makers understand the risks of different policy actions, but at the same time they dislike uncertainty, which jeopardize their efforts to reduce vulnerability.

Our NRT will conduct workshops to train students, faculty, and stakeholders (scientists, planners, business, insurance industry, environmental activists, fishermen organizations, etc.) to communicate risk and uncertainty through a two-way process based on differing perceptions and willingness to accept risk. Trainees will learn communication skills in concert with the audiences with which they will interact during their professions. Participants will discover, learn, share, and practice tools and concepts to understand (mental models, perceptions, needs, limitations, etc.) and engage (media, meetings, citizen science, cooperative learning and research, etc.) with target audiences. The training will support professional development and prepare participants with skills, techniques, and confidence to work together. Case studies will be driven by our research themes (Sect IV) representing regional communities of interest and of place, and the various roles of stakeholders. They will provide learners with an opportunity to develop community-driven solutions to communicate about risk and uncertainty to multiple target audiences differing in awareness, perception of risk, community capacities and connections (social and human capital), coping strategies and willingness to change. **Flaxen Conway,** core member, social scientist, Oregon Sea Grant Extension Specialist, and director of the OSU Marine Resource Management graduate program, will oversee the design and implementation of the communication workshop, based on years of experience in studying the science and practice of communication and engagement with public and marine stakeholders, including commercial and recreational fishing.

(6) **Transdisciplinary group projects**. Trainees will join transdisciplinary clusters combining science and policy expertise to work on a real-world problem inspired by a *client*, who may be

from academia, an NGO, government or industry and has deep knowledge of the scientific and societal aspects of the problem. We envision an intensive two-week academy in which groups work on user-inspired problems in marine science, while supervised by international experts. A holistic goal is to provide an environment in which policy students learn to challenge scientific paradigms, and science students learn to challenge management decisions from a scientific perspective (Ciannelli et al., 2014). A key outcome of this activity will be the identification of a common research question, to which each student may contribute his/her disciplinary expertise, that will become a chapter of the MS or PhD. PI **Ciannelli** will oversee this training element.

(7) **A transdisciplinary dissertation/thesis chapter**
Each student will complete a thesis or dissertation chapter, which represents a novel contribution to transdisciplinary education because the research question will be user-inspired and posed to address a multi-faceted and cross-disciplinary problem (Rosenfield, 1992). Students' collaborative research chapter may share similar introduction and conclusions, but each will have distinctive methods and results. Students may use collaborative software tools such as Basecamp, and the principles outlined during the professional training element, to define projects, brainstorm ideas, build solutions and to record and credit individual contributions. Each student will be guided in this effort by several faculty mentors assigned by the Mentoring Team (see sect. VI).

(8) We will host informal monthly colloquia to promote **peer mentoring**, especially among students entering the NRT program in different years. A cluster of two or three students, who are already engaged in a transdisciplinary project, will present their ongoing work and discuss challenges and benefits of peer-to-peer collaboration among graduate students. Depending on funding availability, the Student Team will invite external guest speakers to these colloquia. Students entering OSU also have access to a variety of non-NRT experiences through their home departments, such as a *Math at the Beach* two-week field course, aimed at refreshing calculus and linear algebra, and a *Cascadia Field Trip*, a camping trip from the peaks of the Cascade Mountains to the shorelines and estuaries of the Oregon coast. Past students have expressed great enthusiasm for the knowledge, social bonding, and sense of belonging to the program and academic unit provided by these activities.

With the addition of an elective in Geography or Oceanography, which is part of the students disciplinary program, the coursework portion of our training elements will fulfill the requirements for a new OSU minor in Risk and Uncertainty Quantification and Communication (Table 2).

III.B Timeline of training

NRT trainees are expected to accomplish the MS in 2-3 yrs and the PhD in 4-5 yrs, consistent with recent traineeship experience in our IGERTs (Fig. 2). Our NRT program will admit students during the fall, in their first year in graduate school during which they will fulfill disciplinary coursework and part of the minor requirements (Table 2, Fig. 2). Trainees will start the NRT professional and research training in their second year. In doing so we leverage student disciplinary knowledge and guide them during the transition from coursework to research, accelerating their path to graduation, thereby addressing concerns about the time investment in cross-disciplinary programs and career opportunities that such programs can entail (Rhoten and Parker, 2004). Students will receive one year of NRT stipend. MS students will be nearing graduation after undergoing the NRT training elements, while PhD students will continue to complete their collaborative dissertation chapters and engage with newer cohorts of NRT trainees. Upon entering the NRT program student and primary mentors will be asked to complete an IDP, following myIDP framework, that is structured around four themes that help students to i) self assess their interest, values and skills, ii) learn about career options, iii) set individual training and professional goals, and iv) implement them, in collaboration with the mentor. The first and second themes of the IDP will help us to assess students' evolution of interest, values and skills while they are in the program. Exploration of career options will inform us on how to tailor the professional training and type of internship that students will undertake while in the NRT (please see also Sect VII).

III.C Connection between the training elements and the interdisciplinary research themes

NRT training elements are aligned with major research activities. Each student will choose either a *science* or a *policy* track based on career aspirations, rather than disciplinary major. In choosing a track, each student defines the role s/he will play in the research cluster and the type of research s/he will conduct within the NRT program. Students in the *science track* will engage in internships and fulfill roles that explore climate variability effects on ocean ecosystems using recent technological advances. These students will develop novel tools for data monitoring, signal processing, model fitting, simulation, and visualization to support data-enabled research. Students in the *policy track* will engage in internship and fulfill roles that explore the dynamics of complex, adaptive social-ecological marine systems. These students will be poised to engage with resource managers to evaluate management strategies and formulate new research priorities that align conservation and societal incentives in ocean science. Trainees in the science and policy tracks will collaborate throughout the NRT except during the internship phase, when they will gain competencies aligned with their research aspirations (Fig. 2).

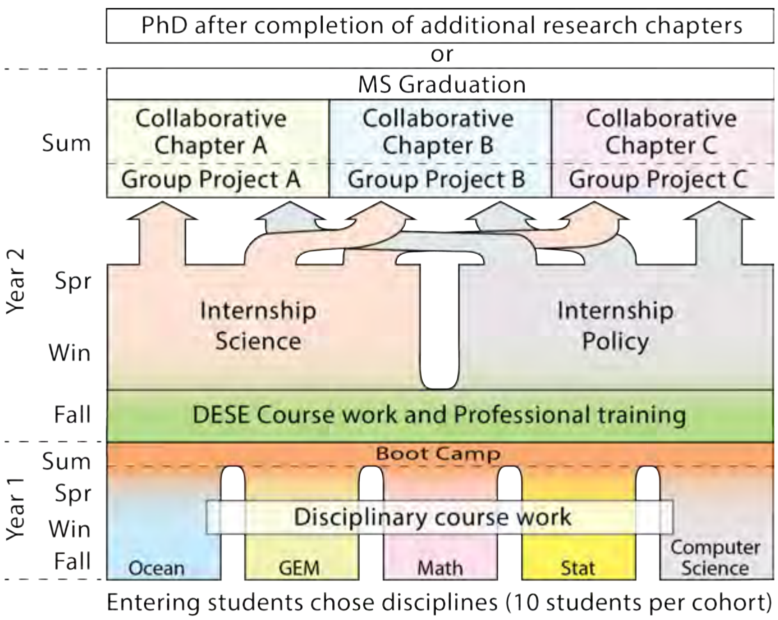

Figure 2. Timeline of NRT training elements. Trainees are recruited in year 1 and start the NRT professional and research training in year 2, after completing discipline coursework in their home departments. GEM includes Geography, Environmental Science and Marine Resource Management.

III.D Innovative aspects of the training model

With a strong emphasis on STEM and communication, our training program integrates all three core DESE activities (information, knowledge, action). The strong STEM influence that underlies our research and training elements, and the focus on training clusters of cross-disciplinary students, are elements of distinction and innovation. Through our program, diverse trainees will experience first hand the common foundations that underpin the mathematical, statistical, ocean and computational sciences, and the complexities associated with science communication and policy making. We adhere to the NRC (2014) model of transdisciplinary research as that accomplished by set of individuals with strong disciplinary knowledge and with breadth to work across fields – T-shaped individuals forming a comb-shaped cluster. We will train teams of students, some of whom have served science internships, others of whom have service policy internships, to conduct joint research on a user-inspired problem. Students with diverse expertise will leverage each other's strong disciplinary knowledge and skills as they collaborate to address complex stakeholder-identified climate and policy problems (Ciannelli *et al.*, 2014).

Our training elements provide evidence-based innovative and potentially transformative approaches to STEM graduate education. Boot camps (first training element), or short and intense teaching modules, foster collegiality, level the playing field among students from different disciplinary backgrounds, and identify new collaborative educational and research opportunities (Rhoten and Parker, 2004). Boot camps are especially instrumental for increasing retention of URM by developing inclusiveness and a sense of belonging (Gardner 2015). Past IGERTs at OSU have demonstrated that well-designed internships (fourth training element) are the primary vehicle by which graduate students obtain hands-on experience, leading to their MS or dissertation research. Transdisciplinary group projects (sixth and seventh training elements) are an effective way to balance the depth versus breadth conundrum of cross-disciplinary programs, and to train students in communication and collaborative work (Goring et al. 2014).

IV. Major research efforts

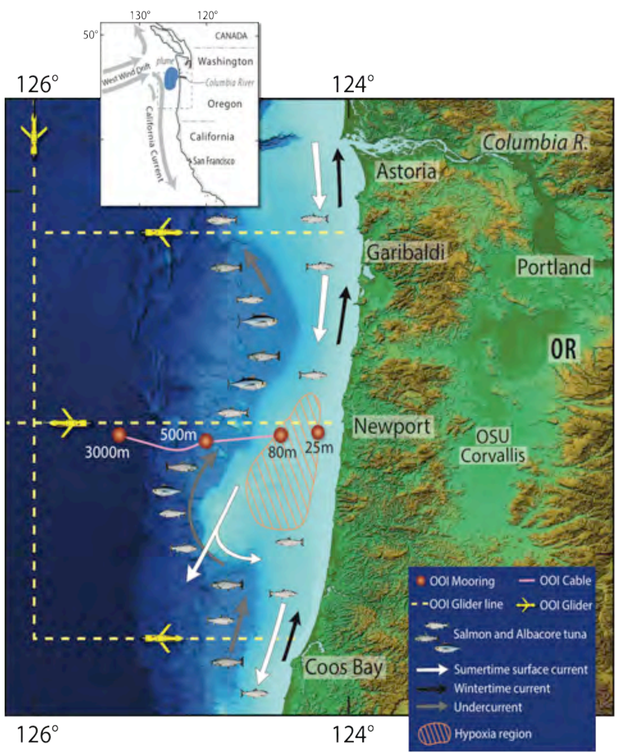

Figure 3. Map of the Oregon coastal zone with dominant water circulation patterns (arrows), fishing harbors, spatial distribution of two commercially exploited fish species (Chinook salmon and albacore), and OOI installations including moorings, cables, and gliders.

We propose research efforts to address Goal 3 of the OSU NRT, namely: *to discover mechanisms that control the response of marine systems to climate change and human pressures*. Our research efforts are driven by (1) scientific and technological developments in marine science that demand training graduate students in STEM and DESE research in marine sciences, and (2) social change and associated risks and uncertainties in marine policy that require cross-disciplinary educational models to communicate and engage with stakeholders. New networks of sensors, such as those installed by OSU faculty involved in the NSF-funded Ocean Observatories Initiative (OOI), enable marine scientists to measure physical parameters with finer spatial resolution, greatly expanding available data (Fig. 3). New models, such as those developed by NRT core member **Alexander Kurapov** at OSU, enable marine scientists to predict physical parameters on time scales that fishermen find useful. Kuparov forecasts temperature, salinity, sea surface height, and other dynamic information accurately at 3-kilometer resolution using his *Regional Ocean Modeling System* and he posts these forecasts on a web site. Many fishermen consult Kurapov’s forecasts when they plan their fishing strategies. A small group of forward-thinking fishermen and scientists – including **Flaxen Conway** (core-member) and **Peter Lawson** (NOAA collaborator in the project) **--** have engaged with fishermen to share technological and catch information in a mutually beneficial collaborative framework. These activities reveal statistical uncertainties about forecasts of weather, climate, and fisheries resource distributions, as well as risk associated with policy actions, such as loss of potential revenue, or overexploiting a resource.

We anticipate opportunities for students to engage in all three areas of DESE research (i. to move from data to information, ii. from information to knowledge, and iii. from knowledge to action) through two transdisciplinary and integrated research themes: a *climate-driven, bottom-up* theme, focusing on the data to information and information to knowledge, and a *policy, top-down theme*, focusing on the impact of DESE and STEM advances on institutions and policy actions. Examples for each theme are provided below. Academia lacks research that addresses marine resource sustainability from both the environmental and the policy side. The proposed OSU NRT research efforts build on ongoing projects, which are combined to create such a transdisciplinary research framework.

IV.A Bottom-up research case study

Climate variability, ocean dynamics and spatial distribution of pelagic fish

Several OSU core members (Ciannelli, Kurapov, Gitelman, Banks, Conway) and collaborators (Lawson) are exploring data on the spatial distribution of Chinook salmon and albacore tuna, iconic and commercially important species in the Pacific Northwest, in relation to environmental and habitat alterations. The research aims to quantify the relationship between catch distributions of pelagic fish, their genetic origin (in the case of salmon), and the ocean environment. We hypothesize that pelagic fish respond to oceanographic features, and that we can project future distributions using predictive oceanographic models. For salmon in particular, we also hypothesize that there are stock-specific (i.e., population-specific) differences in how fish associate with oceanographic features, and that such differences result in diverging spatial distributions. Testing these hypotheses requires accounting for uncertainties in the available data (e.g., due to sampling, space, time) and uncertainties in outputs from predictive models.

Salmon aggregate while in the ocean, but it is not known whether they aggregate with members of the same stock, nor what ocean conditions (e.g., temperature, salinity, current, chlorophyll concentration, etc.) they prefer. If we knew, for example, whether Klamath River salmon stay together in the ocean and, if so, what ocean conditions they seek, then regulators and fishermen could protect these salmon with targeted closures or other policy approaches rather than complete closure of fishery operations from southern California to the Oregon-Washington border, as in 2009. Synthesis of 30 years of tagging data has demonstrated that particular stocks of Chinook salmon have discrete migratory paths in their ocean life phase (Weitkamp et al., 2010). However, the scale and the certainty with which ecological inferences can be made will depend on transdisciplinary synthesis of high-volume, rapidly emerging, varied data.

The Collaborative Research on Oregon Ocean Salmon project (Project CROOS, initiated in 2006) has the capability and experience necessary to accumulate data at the scale required to address the above questions (Ireland, 2010; Bellinger et al., 2014, Satterthwaite et al., 2014). OSU NRT trainees will have access to data from Project CROOS, consisting of catch locations for each individual salmon caught by participating fishermen (NOAA collaborator **Pete Lawson**), genotype of individual fish (core member **Michael Banks**) and background oceanographic information (core member **Alexander Kurapov**). Over 70,000 samples were collected in 2010 through 2014 from California to Washington with additional smaller samples from 2006 and 2007. Other remotely sensed oceanographic features (such as sea surface temperature) are available, and subsurface features can be generated from Kurapov's oceanographic model and OOI products. Using geospatial analysis (co-PI **Jones**), students will test the hypothesis that ocean floor topography contributes to eddy fronts, which are ecotones of high productivity, by testing spatial relationships among bathymetry, eddy front locations from sea surface temperature, and mapped locations of salmon harvests, under warm/cool PDO and El Niño/La

Niña ocean conditions. On the basis of these statistical and geospatial relationships, students will apply Kurapov's oceanographic model to create predictive maps, with quantified uncertainty, of the density of specific stocks of Chinook salmon, which can in turn be used to form harvest strategies that maximize profit for local coastal fishermen while reducing the bycatch of weak and endangered stocks (see next research project).

IV.B Top-down research case study

Assessment of risk and uncertainty of harvest and policy scenarios of pelagic fish in relation to biophysical and economic drivers

This research case study builds on the previous one to generate tools, provide scenarios, and share results for evaluating and communicating risks and uncertainty of different harvest and policy strategies of pelagic fish species, constrained by economic and biophysical factors. We consider both policy and conservation risks, associated with loss of revenue for fishermen due to fishing closures or suboptimal harvest strategies, and loss of local subpopulations due to overharvesting.

Combined with a spatially explicit bioeconomic harvest model, the oceanographic process models and data sets from the bottom up case study provide a tool for evaluating effects of likely management strategies in biological and economic terms, which has been lacking in most fisheries on the West Coast. We propose to use a bioeconomic model system based on the Cobb-Douglas algorithm (well established and currently used to evaluate the North Sea saithe fishery (Simons et al. 2015)) to combine fish stock distribution data with complex fisheries economics. The Cobb-Douglas algorithm (Salz et al. 2011) distributes effort based on a two-dimensional non-linear relationship between effort and local abundance. For this application the model will integrate economics of the fleet (e.g. fishing costs, fish and fuel prices, and fishermen behavior), the impact of fishing on the population biomass, and their spatio-temporal interplay. The economic model will aim at maximizing net profits of the entire fleet, so it involves an optimization routine. The optimization will determine effort adjustment and fishing location, which, in turn, will affect the level of catch of targeted and nontargeted stocks and species (i.e., by-catch), and it can be used to predict the redistribution of fishing effort as conditions and regulations in the system change. Risks from the fishermen's perspective can be quantified as the probability of losing revenue in relation to various harvest strategies. Stakeholder risk can also be quantified as the probability of reaching a certain by-catch quota, which may trigger a moratorium on fishing activities and therefore additional loss of revenue. From a conservation perspective, risk will be quantified as the probability of reaching and surpassing the quota limit on protected species and stocks in relation to different policy actions.

Initially we will test the following scenarios of increasing complexity: (1) Null scenario: optimize harvest constrained by historical species distribution and operational constraints (e.g., 3-day trip duration); (2) Add operating cost to null scenario; (3) Scenario 2, with harvest limits on weak stocks; and (4) Scenarios 1-3 with predicted fish distributions from the species-environment statistical model developed in the previous case study. For each Scenarios 1 to 4 we will estimate the spatial distribution of fishing effort to optimize income, and the probability of loss in revenue compared to existing and observed harvest strategies. We will then conduct virtual management strategy evaluations by testing historical and prospective management regulations, namely: (5) Optimize harvest, constrained by historical species distribution, operational constraints and operating cost, and currently implemented harvest regulations, based on large-scale time and space closures and quota limits. (6) Scenario 5, but with prospective harvest regulations that consider the fine-scale distribution of weak salmon stocks (e.g., temporally and spatially targeted closures), and (7) Scenarios 5-6 with predicted fish distributions from species-environment statistical model. These last three scenarios will allow us to quantify the economic and conservation benefits of implementing new adaptive policies, based on high throughput of genetic, oceanographic and harvest data. Additional management strategy evaluations with more realistic models of harvest strategies will be considered following the initial results and in consultation with industry and manager members. Collectively, modeling results will contribute to our scientific understanding of the marine system and its response to human activities, bridging gaps between the traditional disciplines of resource ecology and social-economic sciences.

An important part of this case study will be the communication of the risks and uncertainties inherent in the model predictions, which will build on the communication workshop (training element 5, Table 1). Framing our scenarios relative to both fishermen and conservation perspectives will facilitate communication among stakeholders and an understanding of various drivers affecting the policy making process. The products of these analyses will be shared with stakeholders through ongoing web-based portals being developed by faculty participants in computer science (co-PI **Todorovic**), oceanography (core-member **Kurapov**) and social science (core member **Conway**). The development of the web portal interface is itself an exercise of communication between stakeholders, scientists and policy makers.

Collectively, our two research case studies will permit NRT trainees to conduct transdisciplinary DESE research on user-specified, real-world problems in marine science and policy, and to build professional experience by engaging stakeholders in resource management decisions. While we only describe marine environmental and economic drivers of salmon life cycle, we are well aware of the many terrestrial drivers affecting salmon population dynamics, such as dams, logging, hydrology and quality of freshwater and estuarine habitats. Should there be an interest from the NRT trainees part to explore terrestrial drivers, our team is well poised to address them, given our expertise on ongoing studies on river hydrology (co-PI **Jones**), estuarine ecology (PI **Ciannelli**), and climate modeling (OSU Climate Center).

V. Broader impacts

This NRT will develop a transdisciplinary research and education program for data-enabled marine science that forges alliances between academia, industry and NGOs and engages scientists, stakeholders and decision makers in ecosystem-based management of ocean systems. Expected outcome will also have an impact policy decisions and on how scientists, fishermen and managers work together in communicating risk and uncertainties of policy decisions and model forecasts. Local, state, and national leaders increasingly rely on insights gained from DESE research for marine policy decisions including spatial management, fisheries management, and climate change mitigation (Berkes, 2011). The OSU NRT will train a new and diverse generation of graduate students in conducting DESE for ocean systems. **Our long-term goal is to train scientists, engineers, and resource managers who can work in transdisciplinary teams in industry, government, NGOs, and academia to create tools and techniques for complex, adaptive social-ecological marine systems**. Students will work on user-inspired problems in climate change, policy, management, risk and adaptation, and will undertake internships in industry, government, and NGOs, benefitting both science and policy. NRT students will gain professional training in communication and how to function in alternative working group structures. Group work on collaborative decisions about complex, real-world issues prepares students as problem solvers for understanding and managing the ocean, the last great frontier on Earth. At the institutional level, the OSU NRT program will be a catalyst to develop a cross-disciplinary minor on risk and uncertainty quantification and communication. The need for such a STEM training is both a national and a regional priority, given that Oregon’s economy is driven primarily by natural resources.

Both programmatic and institutional outcome of the OSU NRT are integral to OSU's ongoing efforts in cross-disciplinary education and in marine science. Our NRT builds on recently hired faculty in cross-disciplinary areas such as geospatial modeling and genomic research, as well as on PI experiences leading IGERT and RCN-SEES grants. This NRT responds to OSU's Strategic Plan 3.0 (May 2014), which identifies Marine Sciences as a top priority. OSU's investment and development of Marine Sciences will include new educational models and new faculty, guided by Dr. Jane Lubchenco (Director of NOAA, 2010-2013, who returned to OSU in 2014). Lorenzo Ciannelli (PI) will serve as a liaison with the OSU MSI, ensuring that NRT curricula and best practices will be adopted as continuing components of graduate degree programs at OSU.

This NRT will aim to increase diversity and broaden participation by increasing the number of graduate students from under-represented minorities (URM) in STEM disciplines. Our NRT will target under-represented groups in STEM disciplines (Hispanics, African Americans, American Indians/Alaska natives, as well as women in computer science, statistics, and mathematics), and we will aim for >50% participation by these groups. To align our program with Oregon demographics, we will also target the many students in the Pacific Northwest who are first generation college, have been rurally isolated, veterans, single parents, or from low income families, who are also underrepresented in STEM. Our URM program is structured around four objectives and associated best practices (described in more detail in section VII).

NRT curricula and program evaluations will be disseminated beyond the NRT program and will inform OSU and wider academic communities on best practices for transdisciplinary education. The assessment of our training model will target participating students, faculty, and stakeholders, and thus will provide a comprehensive understanding of challenges and opportunities for transdisciplinary graduate education in marine science. Internships in NGOs, industry, and government will promote NRT contributions to social issues and post-graduate transitions to careers. Besides serving NRT students, several of our training elements (i.e., communication workshop, professional training, targeted coursework) will be open to OSU guest faculty and NRT mentors, thus expanding the impact of the training models to those who will eventually implement it.

VI. Organization and management

The goal of the organization and management structure of this NRT is to promote a sense of community and identity in the NRT through involvement and inclusion of project participants (faculty, trainees, the evaluator, staff, and collaborators) (Figure 4). Roles include:

1. **NRT PI** (Lorenzo Ciannelli). The PI will provide research and training leadership to the NRT and: (1) liaise with NSF, the Graduate School and participating OSU Colleges; (2) manage the budget (with ET and PC); (3) coordinate advertising and outreach; and (4) oversee reporting, performance, and evaluation (with EE). Dr. Ciannelli is widely published on fish spatial ecology and has led 15 multi-year and multi-PI research projects, including NSF – SEES and NOAA –CAMEO cross-disciplinary grants. He is developing curriculum material to bridge socio-ecological barriers in marine resource management graduate programs (Ciannelli et al., 2014, NSF-funded SEES project, 1140207) and is a member of the MSI curriculum committee. He received the Jack Diamond Excellence in Mentoring Award from OSU's College of Earth, Ocean, and Atmospheric Sciences in 2010.

2. **Executive Team** (ET) (PI and co-PIs). The ET provides the primary leadership of the NRT. They will foster a sense of community among project participants through quarterly meetings to: (1) devise strategies for continuous program growth and development based on the outcome of the assessment and performance metrics (see sect VIII); (2) award stipends; (3) establish and implement recruitment policy, including diversity initiatives; (4) oversee curriculum and internships; (5) enhance mentoring; (6) respond to student feedback, (7) organize tutoring for students in academic difficulty, and (8) monitor and oversee dissemination and public outreach. In addition the ET will oversee recruitment, curriculum and mentoring through three sub-teams, as described below.

2.1. **Recruitment and Diversity Team.** This subset of the ET will oversee recruitment and admission activities and achieve diversity goals for recruitment and admission (see sect VII). They will review student applications and provide recommendations to the Executive Team.

2.2. **Curriculum and Internship Team**. This subset of the ET will: (1) review courses, programs, and student evaluations; (2) identify internships and coordinate training and outcomes for students and host; and (3) recommend curriculum changes to the ET, following formative evaluations (see sect VIII).

2.3. **Mentoring Team** This subset of the ET will: (1) solicit student feedback; (2) match trainees with faculty mentors; and (3) monitor Individual Development Plans and mentoring.

3. **Project Coordinator** (PC). We have budgeted funds for six months/year of administrative support. The PC will: (1) serve as the central point of communication for administrative and academic matters; (2) monitor budgets and finances; (3) assist Curriculum, Recruitment, and Mentoring Teams; and (4) assist with logistics. We will select an individual with and MS and experience as a graduate student coordinator.

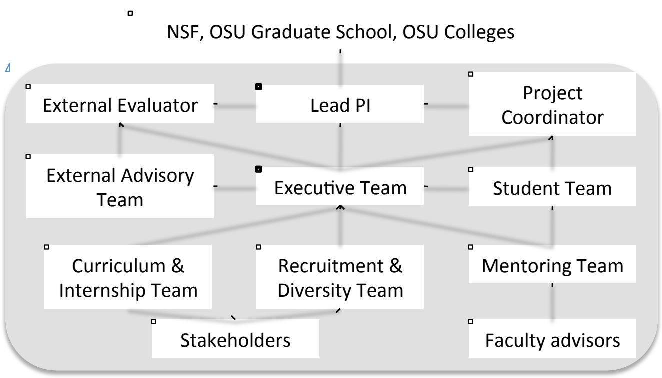

Figure 4. Organization, management and reporting lines for proposed NRT-DESE in marine science and policy.

4. **Student Team** (4 NRT trainees). This team will: (1) foster a sense of student identity, by seeking feedback, selecting speakers, and organizing events; (2) coordinate with Mentoring Team; (3) provide feedback to Executive Team; (4) serve as peer mentors.

5. **The External Advisory Team** (EA). The EA will: (1) conduct an annual feedback evaluation of our NRT trainees; (2) communicate with the NRT leadership and external evaluator (Char) regarding the outcome of the annual evaluations; and (3) provide guidance to institutionalize successful NRT training models. The EA Team will include two senior professors outside of OSU known for their research and education in computer science, statistics, or marine/aquatic science; two members from government (e.g., NOAA) or industry, and one member of the OSU graduate school. Reviews will occur annually for the five years of OSU NRT program, and one additional review will occur four years after completion of the program when all students have graduated.

6. **External evaluator** (EE). The EE is Cynthia Char, from Char Associates; she will report to the PI and ET and will coordinate activities with the EA (Fig. 4) (see sect VIII).

7. **Faculty advisors.** Each NRT trainee will have a faculty advisor, who will (1) mentor the student, (2) participate in the professional training elements of our program (communication, work group function), (3) attend the annual NRT all-hands meeting, and (4) participate in formative evaluation activities and discussions of program changes. Additionally, each NRT trainee will be mentored by a team of cross-disciplinary faculty during the group project and collaborative chapter.

8. **Stakeholders**. We will engage with groups involved in regional marine science and policy from industry (e.g., commercial fishing), government (e.g., National Marine Fisheries Service, National Center for Atmospheric Research, Oregon Department of Fish and Wildlife), and non-governmental organizations (e.g., Oceana, Environmental Defense Fund).

In addition to the described committees and functions, each year during the NRT boot-camp there will be an annual "all-hands" meeting to discuss academic development, administration, funding, and new lines for research and training. The all-hands meeting will also be a venue for students to present their work (symposium), and communicate evaluations of the program by the External Advisory Team. Internship hosts and past OSU IGERT alumni (see Sect IX) will also be invited to participate.

VII. Recruitment, mentoring, and retention

Recruitment and mentoring in the NRT on marine science and policy address Goal 4: *Develop and apply evidence-based practices for recruiting, training, and retaining students and for placing them into successful careers, with an emphasis on underrepresented minorities in STEM.*

VII. A Recruitment

We will recruit NRT trainees in three cohorts of ~10 students (years 1, 2, and 4). The PI and ET will coordinate advertising and the Recruitment Team will seek out prospective students by visiting REUs, minority-serving conferences, and minority-serving institutions (details below). The minor in risk and uncertainty will be open to all graduate students at OSU. Students will be recruited in the NRT program in their first year, during which they will undergo coursework for their departmental and minor requirements (Table 2). The bulk of the NRT professional and research training will start in their second year (Fig. 2). The PI and PC will advertise the NRT nationally through relevant professional outlets and listservs. Each NRT applicant will submit a personal history essay and summary of the first step of the IDP (Table 3). The Recruitment Team will select applicants based on these materials, transcripts, GRE scores, and recommendation letters.

Table 3. Individual Development Plan (IDP) metrics for assessment of each training element of the OSU NRT-DESE in marine systems. IDP metrics are based on: (A) skills, values, interests assessment; (B) evaluate career options; (C) set goals to improve skills, build network, and gain experience; (D) recruit mentors. F=formative; S= summative.

Training elements	Metrics for assessment			
	Skills	Career	Goals	Mentor
1. Boot camp: field visit, meet stakeholders*	F	F		
2. Targeted coursework*		F	S	
3. Training on work group function*	F		S	
4. Internship		F		F,S
5. Communication workshop*			F,S	
6. Group project	F		F,S	
7. Thesis chapter			F,S	F
8. Peer mentoring seminar*	F			F,S
* part of new graduate minor at OSU in "Risk and Uncertainty"				

VII.B Mentoring

The Student Team will coordinate with the Mentoring Team (Fig. 4) to identify a faculty mentor, who will commit to regular meetings and an Individual Development Plan to (1) develop trust and trainee confidence, (2) identify trainee's values, skills, and interests, (3) establish a long-term plan and career goals, (4) evaluate and adjust the plan based on trainee experiences, and (5) enlarge the trainee's network of mentors (Table 3). Each trainee will have a funding plan and NRT faculty advisor for the full duration of the degree program.

VII. C Retention

Participating departments at OSU enroll about 40 MS and 18 PhD students each year; retention is 80-98% and time to graduation is 1.9-2.5 years for MS to 3.7-6.0 years for a PhD. These metrics are respectively higher and shorter than national averages for similar disciplines (CGSETS, 2010; NSF 2006). Our retention plan is based on evidence-based mentoring best practices designed to counteract social isolation, disengagement with program goals, and academic difficulties, which contribute to poor retention (CGSETS 2010, 2012). Our education plan (sect III) is based on *collaborative projects, cluster mentoring* and *early professional engagement*, skills that are critical for both academic (Morse et al. 2007, Lagholz and Abele, 2014) and nonacademic (Blickley et al. 2012) careers. Collaborative projects will provide peer and faculty mentoring, reducing social and academic isolation; tutoring will counter academic difficulties; and professional training on communication, work group function, and internships will assist trainees to align their unique skills with professional careers.

VII.D Building diversity

To increase diversity and broaden participation we propose a comprehensive plan built on evidence-based best practices (Sowell et al. 2015, Gardner 2015) expressed as four objectives:

Obj 1: Inspire and recruit URM students for graduate studies in marine science and policy. The Recruitment Team will (1) coordinate with the PNW LSAMP and the NOAA Living Marine Resources Cooperative Science Center (LMRCSC) to conduct an annual research conference to bring under-represented minorities (URM) students in marine science and STEM to OSU to introduce them to opportunities in marine science and policy; (2) invite students to apply to NRT from research experiences for undergraduates (REUs) at OSU, including Hatfield Marine Science Center and Ecoinformatics Summer Institute; (3) attend minority conferences, i.e., the Richard Tapia Conference on Computing, the Math Alliance's Field of Dreams conference, the Infinite Possibilities Conference for women and minorities in mathematics and statistics, the American Society of Limnology and Oceanography's Multicultural Program; (4) seek applicants from the Ecological Society of America's Strategies for Ecology Education, Development and Sustainability (SEEDS); (5) participate in activities at the five OSU Cultural Centers for women, blacks, Asian and Pacific Islanders, Hispanics, and Native Americans) to encourage OSU minority students to attend graduate school in marine science and policy; and (6) invite applicants from the National Name Exchange, an online database of URM students.

Obj 2: Increase admissions of URM students to graduate programs in NRT-DESE. The Recruitment Team will (1) advocate for minority admissions with each participating college at OSU; (2) comply with OSU Graduate School efforts to promote graduate student success (e.g., Graduate Student Success Guide); (3) evaluate applicants' personal history essays, which may highlight diversity, economic and educational disadvantages of URM applicants; (4) consider student affiliation with graduate prep programs such as McNair Scholars, the Posse Foundation, Gates Millennium Scholars, College Success Foundation in admission decisions; (5) call and email prospective students; (6) arrange visits to NRT activities for students on campus and in OSU REUs, to meet with faculty and peer recruiters.

Obj 3: Retain URM students to completion of MS or PhD in NRT-DESE. The Executive Team will (1) admit URM students with full funding for the degree program; (2) nominate URM students for OSU Diversity Advancement Pipeline fellowships; (3) organize tutoring; (4) organize group activities such as boot camp and communication workshop. The Mentoring Team will (1) match trainees with advisors; (2) track the mentoring success; (3) connect students with tutors for STEM skills; (4) promote student groups that foster community (e.g., "Hydrophiles").

Obj 4: Place URM graduates in careers relevant to their NRT-DESE training. The Executive Team and Project Coordinator will (1) engage graduates of past OSU IGERTs and stakeholders on External Advisory Team to develop internship opportunities; (2) communicate internship opportunities to trainees; (3) match trainees with internship mentors and evaluate compatibility with prospective employers; (4) review evaluations of success of training elements on work group function and communication to assess skills gained from internships and trainee readiness for employment; and (5) conduct mock interviews and related job interview training.

VIII. Performance assessment/project evaluation

Performance assessment and project evaluation address goal 5 of the OSU NRT program: *Evaluate and disseminate our programmatic elements for conducting transdisciplinary research and education and for broadening participation of underrepresented minorities in STEM*. The external evaluation will be conducted by Char Associates, an educational consulting firm specializing in program evaluation. The evaluation will span both formative and summative elements, and assess the project's effectiveness and impact upon participating students, faculty, administrators, and the host institution (OSU). The primary evaluation questions are: *"To what extent, and in what ways, did the NRT project successfully: 1) Educate and train future scientists, engineers, and resource managers to work in transdisciplinary teams using DESE tools and* *techniques*, and 2) *promote a transformative and scalable new marine science and policy education program that teaches students to quantify and communicate risk and uncertainty*?

VIII. A Formative Evaluation

During Year 1, Char will work closely with project staff and core faculty to develop a project logic model, a visual schema representing the project's theory of action, outlining key resources and program activities linked to the desired outputs, outcomes, and impacts (Kellogg Foundation, 2004). Char will use the logic model to provide a conceptual framework for both formative and summative evaluation to critically examine how specific elements of the NRT training program are expected to lead to the desired student, faculty and institutional outcomes. Based on evaluation results throughout the project, Char will refine the logic model to produce an evidence-based theory of action representing the transformative elements of this marine science and policy education program in year 5.

The initial logic model work will inform the formative evaluation of training elements. Char will work with core faculty to create embedded performance measures for the various training elements (Table 1), particularly NRT's unique elements: the boot camp, the professional training module on collaborative working structures, and the group project. Char also will design a formative feedback form to gather trainees' self-assessments of their learning, critiques, and suggestions for training elements relative to the four learning outcomes (See Section III). Formative evaluation results will be shared within three months of the completion of the element.

Char will also design a post-program reflective feedback form that faculty will complete to evaluate the successes and challenges, mid-course adjustments, and future revisions for each teaching element they have delivered. These forms will be discussed by the curriculum and internship team and during the final summative evaluation in Year 5.

VIII. B Summative Evaluation

The summative evaluation will use a "convergent-parallel" mixed-methods design (Creswell & Plano Clark, 2007), to utilize both quantitative and qualitative data to elucidate student, faculty and institutional impacts from the program.

<u>Student Impact</u>: Char will conduct a longitudinal study of all participating NRT trainees to assess the program's impact on (1) their acquisition of knowledge, skills and disposition to conduct transdisciplinary, collaborative DESE research pertaining to the project's four learning outcomes, and (2) the progress of their graduate and post-graduate careers. Primary data sources will be the Individual Development Plans (IDP) (Table 3) completed by each trainee at the beginning and end of his/her degree, as well as annual student surveys. Additional data from annual interviews (8 students in each cohort: 4 from each track) will reveal trainees' views on the affordances and challenges of engaging in transdisciplinary, collaborative DESE research. The interview sample will include URM students in order to discern particular programmatic features that enhanced, or hindered, their pursuit of STEM endeavors (May et al. 2008).

Char will also gather a selection of student work samples (e.g., internship projects, collaborative research chapter, dissertation abstracts) and analyze these across a variety of dimensions pertaining to the four learning outcomes, such as interpreting data from multiple sources, addressing needs of stakeholders, and trans-disciplinary problem-framing and solutions.

Metrics will include survey and IDP data concerning trainee knowledge, skills, and aspirations to conduct transdisciplinary, collaborative research in DESE, as well as indicators such as NRT course grades, pursuit of the new "Risk and Uncertainty" graduate minor, STEM internships and job placements in graduate and post-graduate careers, conference presentations, peer-reviewed publications, and other metrics drawn from previous national evaluations of IGERT programs (Carney & Neishi, 2010; Carnell et al., 2006; Gamse et al., 2013; Giancola et al., 2001). Char will also employ the T assessment tool (August et al., 2010), to specifically measure trainee self-perception of knowledge and interest in cross-disciplinary inquiry.

VIII. C Faculty and Institutional Impact

In Year 1, Char will survey project staff, OSU faculty and administrators to assess OSU's (1) current institutional climate and practices for cross-disciplinary teaching, research and work practices, and (2) organizational partners and capacity for partnerships. In Years 2-4 faculty and mentors will complete the IDP and T assessment tool, to gauge faculty growth in interdisciplinary endeavors over time. In Year 5, Char will survey project staff, OSU faculty and administrators, to assess the effect of the NRT on faculty teaching and research, academic programs, institutional policies, and graduates' preparedness for the workplace. In Year 5 Char will also re-survey core members of project staff, reflecting on their responses from Year 1, their post-training feedback forms, and other insights gleaned over Years 1 to 5. Char will also conduct a document analysis

Table 4. Time for evaluation for each year of the OSU NRT

Evaluation Timeline of Data Collection	Y1	Y2	Y3	Y4	Y5
Formative Assessment: Performance measures; student/faculty feedback	x	x	x		
***Summative Assessment*:** Student surveys, IDP's	x	x	x	x	x
Student interviews		x	x	x	x
Course grades, internships, job placements, publications and presentations		x	x	x	x
Document analysis of student work samples		x	x	x	x
T-assessment metric with students and faculty		x	x	x	x
Faculty/administrator surveys	x			x	x
Document analysis of program offerings and policies	x				x

on a selection of institutional work samples (changes in program offerings, minors, and multi-disciplinary team-teaching offerings in course catalogues; policies in faculty handbooks; mission statements on department and OSU college websites) (Table 4). Char will communicate regularly with project staff through video conference meetings, site visits, and observations of key training elements throughout the project. Char will submit research memos with program recommendations to project staff twice a year during the formative evaluation phase (Years 1 and 2), and a full report summarizing formative evaluation findings in Year 3, as project staff revise training for the final cohort. Char will provide a report on initial summative findings in Year 4, and a final evaluation report in Year 5. Char will disseminate evaluation results through submissions to peer-reviewed journals and conferences (e.g., *Journal of Research in Science Teaching*; annual conferences of the National Association for Research in Science Teaching and the American Educational Research Association).

IX. Recent student training experiences

The team of PIs and investigators involved in this NRT proposal has a successful record in building cross-disciplinary research programs at OSU, including two IGERT projects. This proposal is based on a previously submitted NRT proposal that received positive reviews from NSF. From 2003 to 2011, OSU supported the Ecosystem Informatics IGERT (NSF 0333257). Two core-members in the current proposal (Jones, Thomann) were listed as investigators on that IGERT; a third NRT participant (Waymire) served in a key scientific teaching, research, and advisory role for the entire 2003-2011 funding period. The IGERT supported 36 PhD students from 12 programs in four colleges (Agriculture, Engineering, Forestry, Science) in cross-disciplinary PhD research and training linking ecosystem studies, computer science, and mathematics; 18 of 36 students were from targeted, underrepresented groups and 43% were women. All students have defended their degrees (retention 100%), and all are employed at academic institutions (e.g., Duke, Colorado State, Tulane), in domestic and international government agencies (e.g., NCAR, NOAA, USFS, CSIRO), or in industry (e.g., Nike). The Ecosystem Informatics IGERT produced more than 200 peer-reviewed publications (http://ecoinformatics.oregonstate.edu/).

X. Results from prior NSF support

NSF Grant 1140207 (PI **Ciannelli**) $749,000, 2/2012–1/2016. *RCN-SEES: Sustainability of marine renewable resources in subarctic systems.* Intellectual merits: Our scientific goal is to integrate basic eco-evolutionary and socioeconomic principles to address the consequences of current and alternative policy practices in large and commercially exploited marine ecosystems. We bridge a gap among ecologists, mathematicians, social scientists and resource managers to provide a sound science support system for conservation. We focus on subarctic marine systems, which are highly productive, intensely exploited, susceptible to climate variability, and under-represented in socio-ecological literature. Broader impacts: Our educational goal is to train research and management scientists in the cross-disciplinary fields of ecology, oceanography, evolution, sociology and conservation. We expose young scientists to the crosscutting disciplines and issues related to sustainability in marine fisheries and to foster sustained, cross-disciplinary interactions among early and advanced career scientists at national and international institutions. As part of this grant we conducted a summer academy on transdisciplinary marine research for sustainability. Fifteen graduate students and early career professional attended the academy and will present heir work at special session of the 2015 American Fisheries Society meeting in Portland. Publications to date: six.

NSF Grant 0823380 (coPI **Jones**) $5,800,000, 12/2008-11/2014. *Long-term ecological research at the H.J. Andrews Experimental Forest LTER: LTER6.* Intellectual merit: The goal of the Andrews Forest LTER program is to study long-term ecological processes in mountain forest and stream ecosystems in the Pacific Northwest. Funded for six LTER cycles, since 1980, the Andrews Forest sixth cycle (LTER6) focused on the theme of complex topography and its influence on interactions between drivers and ecosystem responders. Major findings included: 1) flows of air and water are episodically coupled to, and decoupled from, regional patterns; 2) interactions of topography and atmospheric dynamics limit generalizations about elevation-dependent warming effects on ecosystem processes and biodiversity; 3) tree mortality in mature and old-growth forests is increasing, possibly as a result of climate change, but the mechanisms are not well understood; and 4) leaf and insect emergence varied by >40 days between years and from low to high elevation within a year, and birds seek sites of low temperature variability. Broader impacts: 1) recent policy and land-use change may be reducing biodiversity associated with meadows and early successional habitats; 2) disturbance and land-use history have a lasting imprint on carbon and hydrology that may be overriding climate change and topographic controls; 3) social forces have strongly limited use of ecologically-based forest practices, and a decision point for determining the future of forestry on federal lands appears imminent. LTER6 produced 200 peer-reviewed publications.

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