fish610.2 Ecological Considerations of EAFM

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http://mareframe-fp7.org

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Contents

1 Individual Considerations

1.1 Learning Objectives

1.1.1 Details

Learning Objectives 1

- Explain why individual characteristics such as body size should be included in an EAFM framework
- Explain why variation in phenotype, behavior, and physiology among individuals should be included in an EAFM framework
- Explain how individual considerations can be incorporated into an EAFM plan

1.2 Introduction to Individual Considerations

- Ecological scaling (Individual to ecosystem)
- Why include the individual level
- Individual components to be considered

1.2.1 Details

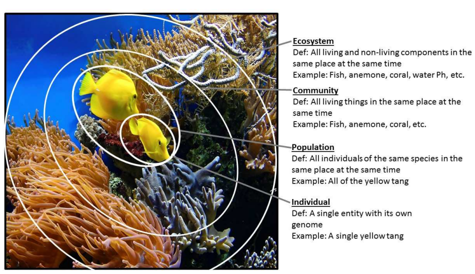


Figure 1: Levels of ecological organization.

Why Include the Individual

When including individuals within an EAFM framework one is really considering the variation among individuals within a population, i.e. phenotypic differences, physiological differences, behavioral differences, etc. Variation or problems at the individual level can often cascade to the population, community, and even ecosystem level and are therefore an important component in developing an EAFM management plan. For example, environmental factors can influence cellular processes and organ function which combine to impact individual fitness which drives population-level processes and can effect ecosystem structure and function [Ward et al., 2016]. In other words, individual variation should be included within an EAFM framework because variations in individuals transfer directly to how the population functions and links the population to its ecosystem.

Important Individual Components

According to Ward et al. [2016] there are several individual characteristics that warrant consideration when developing an EAFM management plan:

- Sex-based differences
- Phenotypic variation
- Body-size differences
- Behavioral variation
- Physiological variation

The reason it is important to consider these characteristics as well as how they are incorporated into an EAFM management plan will be covered in the subsequent slides.

1.3 Sex-Based Differences

- Define sex-based differences
- Explain the impact of sex on catchability
- Explain what causes sex ratios to be altered (including examples)
- Impact of altered sex ratios on ecosystem ecology

1.3.1 Details

What are Sex-Based Differences

When discussing sex-based differences within an EAFM framework one is looking at the differences between the sexes and how they impact mating systems. Thus, characteristics that vary among individuals such as size, behavior, and rate of maturity should be looked at. These characteristics are of interest because they impact the catchability of an individual which can alter sex ratios and subsequently mating system and the ecosystem.

Catchability, Sex Ratios, and Populations

Fisheries tend to select for the largest, fastest maturing, most active, most aggressive individuals [Stokes and Law, 2000, Rowe and Hutchings, 2003]. As a result, these individuals are removed from the mating pool reducing phenotypic variation within the population. Typically, these individuals are also the preferred mates, so, removing them from the population can result in reduced reproductive investment and fertilization rates and in turn decreased offspring viability [Sheldon, 2000].

These characteristics (larger size, quicker maturity, and more active and aggression) also tend to be more prominent in males which means fisheries are preferentially selecting males skewing the sex ratio. Having a female favored sex ratio can reduce reproductive success by decreasing the probability of encountering a suitable mate. This is especially true if the sex being selected for is the "choosie" sex, i.e. the one the selects the mate. A female skewed sex ratio can also reduce fertilization rates by reducing the amount of investment females place on reproduction. For example, female Banggai cardinalfish, *Pterapogon kauderni*, provide more resources to their eggs when they mate with a "desirable" male as apposed to a lesser male [Kolm, 2002].

Reduced reproductive rates from skewed sex ratios have been found to increase the rate of population decline and decrease the recovery rate [Rowe and Hutchings, 2003]. The relative impact on population decline and recovery increases as the

1. intensity of mate competition increases
2. importance of mate fitness increases; and
3. sex bias becomes more extreme within a commercial fishery

As the desire by commercial fisherman to catch larger individuals increases the male to female ratio becomes more skewed potentially increasing mate competition among females and increasing the importance of finding the fittest male. These impacts in turn affect the rate at which a population declines or recovers from a decline. Thus, the selection for large individuals has the potential to increase the rate of population decline and decrease the rate of recovery. As a result, it is important for managers to consider the implications of size regulations on individuals when developing a management plan.

Case Study 1: Atlantic Cod

Cod are broadcast-spawners with significant size and behavioral variation among individuals. Female cod reach sexual maturity between 2-7 years of age and between 35-85 cm in size. Cod release their eggs over a 3-6 week period within a 6-12 week period. The number and size of eggs also varies among individuals as well as the depth with which they are released.

During the spawning season, males tend to be deeper in the water than females as a ventral mount is required for mating. This behavior, however, increases the susceptibility of males to fishing gear (the fishing gear is deployed on or near the bottom) altering the sex ratio during the mating season. The sex ratio may be further altered by the largest most territorial males being more likely to be harvested. This may result in reduced quality and size of males, i.e. higher quality males are deeper in the water and more active. Reducing the quality and size of males available to females, who are thought to be the choosers, may negatively affect reproduction in several ways

- Male and female cod need to be relatively equal in size to reproduce. Thus, if large males are preferentially removed from the population then large females will have fewer mate options.
- Females may require more time to find an adequate mate altering the reproductive season.
- Delayed spawning could result in over-ripening of gametes reducing the probability of fertilization and developmental success of the

offspring.

The impact on reproduction may negatively impact the population as a whole. Specifically, reducing the size of cod reproducing successfully has been found to truncate the average body size for a population. For example, the mean individual mass of northern cod in Newfoundland decreased by 50% between 1962 and 1991 (a period of overexploitation resulting in a population crash). The reduced size variation is a result of reduced genetic variation. Thus, the recovering population will have less genetic material to select upon.

This case study was adapted from Rowe and Hutchings [2003].

1.4 Phenotypic Variation

- What is phenotypic variation
- Examples of phenotypic variation
- Why phenotypic and life history variation should be included

Phenotypic variation expressed as pattern and coloration differences in *Donax variabilis*. Photo was taken by Debivort.

1.4.1 Details

What is Phenotypic Variation

Definition 1: Phenotypic Variation

Phenotypic variation is the variety of observable traits within a population.

Phenotypic variation typically results from genetic variation and/or an individuals response to environmental conditions (including the selective pressures of fishing). Phenotypic variation can be expressed as differences in development, morphology, phenology, behavior, and products of behavior among individuals. Specific examples of phenotypic variation include scale coloration, body size, and aggressive behavior.

1.4.2 Why Include Phenotypic and Life History Variation

Phenotypic and life history variation should be included within an EAFM framework for several reasons:

- Fishing mortality can drive shifts in phenotypic variation by selecting for particular characteristics and thus removing that genetic material from the population, i.e. selecting for large fish

- Individuals within a population are often linked based on the differences in life history, i.e. variation in dorsal fins in cod impact which individuals can mate together

- Variation impacts the resilience and adaptability of a population to environmental change

- Variation in traits like maturation and reproduction can influence the vulnerability of a population to decline from harvesting

It is important to look at both phenotype and life history variation as phenotypic variation occurs on the individual level but manifests itself in life history shifts at the population level. Thus, significant changes in phenotype variation can cascade to changes in the population, community, and ecosystem.

1.4.3 Further Reading

For more information on phenotypic and life history variation and its inclusion in an EAFM framework see Ward et al. [2016].

1.5 Variation in Body Size

- Causes of body size variation
- Impact of body size on catchability
- The types of fish which should have body size included within an EAFM management plan

Body size variation in Chinook Salmon. Photo taken by Paul Frater.

1.5.1 Details

Causes of Body Size Variation

A fish's body size is a result of its sex, energetics, genetics, environment, and health with the greatest impact coming from energetics [Ward et al., 2016]. More specifically, how a fish acquires and allocates its resources, i.e. how much energy an individual puts into reproduction, maintenance, growth, etc., is the largest determinant for body size. However, metabolic processes must be maintained prior to inputting energy into extraneous features such as reproduction. Thus, metabolic rates provide a baseline for variation in body size. Remember that metabolic rates vary by mass and temperature such that larger fish expend proportionally less energy for metabolic function than smaller fish.

Why Include Body Size Variation

As discussed in the sex-differences slide, larger more active individuals are more likely to be harvested than smaller, less active individuals. The size bias resulting from fisheries can impact both the individual and population level. Specifically, typically larger individuals experience energetic and ecological advantages that increase their fecundity, they may also invest more energy into reproduction. The offspring of these large individuals also tend to experience increased rates of maturation and decreased sensitivity to food shortages increasing their overall fitness [Ward et al., 2016]. Thus, the selective removal of large individuals via fishing mortality could negatively impact the reproductive success and decrease body size variation within the population impacting long-term resilience and recovery. As a result, it is important to incorporate body size variation into EAFM planning.

Another reason it is important to include body size variation into an EAFM framework is because body size impacts the behavior of individuals. Body size influences:

- hierarchical structure - larger fish tend to be higher ranking
- resource and mate competition - larger fish tend to out-compete smaller fish
- schooling behavior - fish of similar size tend to align together when schooling
- predator-prey dynamics - advantageous for predators and prey to be larger (can more easily metabolism small prey and can avoid smaller predators via gape restrictions, respectively)

Further Reading

For more information on body size variation and its inclusion in an EAFM framework see Ward et al. [2016].

1.6 Behavioral Variation

- Examples of behavioral variation
- How behavioral variation impacts catchability
- Why behavioral variation should be incorporated

1.6.1 Details

Examples of Behavioral Variation

When discussing behavioral variation within an EAFM framework we are concerned with the actions displayed by individuals and how these actions vary among individuals both within and among populations. Behaviors of interest include: territory defense, boldness, and migratory behavior. Differences in these behaviors can result from differences in life history stage, i.e. juveniles and adults behave definitely, and physiological differences, i.e. a healthy individual and a diseased individuals behave differently, among other things.

Why Include Behavioral Variation

Inclusion of behavioral variation allows for another avenue of addressing vulnerability to exploitation, impact of altered environmental factors, and understanding population shifts in genetic/phenotypic differences. For example, the boldness of an individual has been linked to catchability. Biro and Post [2008], found that bold, fast growing rainbow trout, regardless of body size, were more susceptible to commercial fisheries than shy, slow-growing individuals. This difference is attributed to the risk-taking potential of bold fish. Because bold fish are more likely to partake in risk-taking behavior they are also more likely to be caught.

Behavioral differences can also provide insight into environmental changes. Environmental changes, such as food deprivation, have been linked to physiological changes which can result in consistent behavioral differences and in some cases phenotypic variation. Killen et al. [2013] noted that thermal stress can result in behavior suppression for all individuals following severe or rapid temperature changes altering the individuals metabolic rate and aerobic capacity. Altering the metabolic rate, would have proportionally greater impact on small fish which are not as efficient metabolically, potentially shifting size distributions if the stress is prolonged.

It is especially important to include behavioral variation for long lived, slow maturing species as the differences tend to be more significant. These species also tend to be more vulnerable to over fishing.

Further Reading

For more information on behavioral variation and its inclusion in an EAFM framework see Ward et al. [2016].

1.7 Physiological Variation

- What is physiologic variation
- Why should physiologic variation be included
- How physiologic variation impacts catchability

1.7.1 Details

What is Physiologic Variation

Physiological variation refers to the differences in physiological processes among individuals. In the case of physiologic variation at the individual level, EAFM is particularly concerned with metabolic processes such as metabolic rate, aerobic capacity, water retention, etc.

Why Physiological Variation Should be Included

Physiology plays several key roles at the individual level which can impact the ecosystem and thus are encouraged to be included within EAFM management planning. Specifically, physiological changes often act as a link between the environment, an individuals behavior, and an individuals fitness. Similarly, an organisms tolerance and response to stressors is often a result of its physiological limits. Thus, the conditions in which an organism can survive and reproduce are a result of its physiological processes. As a result, physiological variation can be an important component in the calculation of natural mortality, which is usually an area of high uncertainty in ecosystem models.

Further Reading

For more information on physiological variation and its inclusion into EAFM see Ward et al. [2016].

1.8 Incorporating Individuals into an EAFM Framework

- Summary of why to include individual variation
- Incorporating individual considerations into reference points
- Incorporating individual consideration into models (EwE and Atlantis specific examples)

1.8.1 Details

Summary: Why Include Individual Considerations

Considering individual variation within EAFM planning is important from a cascade perspective. As has been previously pointed out, variation at the individual level impacts the genetic material being passed on and in turn the population structure which can alter predator-prey dynamics and subsequently the structure, function, and resilience of the ecosystem as a whole. Conversely, ecosystem level changes, such as changes to dissolved oxygen (DO) content, can impact the physiology of an individual which can impact catchability and mate selection again resulting in population and potentially community level changes.

Incorporating Individual Considerations - Reference Points

For the reasons previously addressed, it is important to consider individual variation when developing an EAFM management plan. However, inclusion of all modes of variation is impossible. Therefore, it is of the utmost importance to carefully select the individual considerations which are the most important in a particular ecosystem. To assist with this issue, Ward et al. [2016] suggests monitoring and maintaining detailed life-history information including morphology, physiology, and/or behavior data and deriving benchmarks based off of this information. Utilizing these benchmarks, reference points can be derived that address the impact of shifts in individual variation on ecosystem-scale processes. Like all reference points, they should be fluid and in turn adaptive to changes at all environmental scales.

When developing reference points it is important to consider the projected environmental changes. Changes in environmental conditions from habitat preservation may alter the phenotypes displayed by individuals and thus significantly impact their condition in relation to its associated reference point. For example, metabolic rate and growth rate appear to be positively correlated when food availability is high but negatively correlated when food availability is low. Thus, within a management would want to account for how changes in food availability will impact the functionality of the individual.

Assignment 1

Read Andersen and Beyer [2015], complete the following simulations using the simulation applet in Appendix E: Web-based implementation, and answer the associated questions.

Simulations

	W_∞	α	η_m	ε_a
Simulation 1				
Simulation 2				
Simulation 3				
Simulation 4				
Simulation 5				

Questions

Incorporating Individual Considerations - Ecosystem Models

When incorporating individual consideration into an EAFM framework the aim should be to

- assess the risks associated with different management strategies
- attempt to reduce the probability of altering the populations sex ratio
- reduce the impact of fishing during spawning
- ensure that fishing does not significantly impact genetic variation

To accomplish this, managers use statistical models to analyze the collected data. The data needed to adequately include individual variation into ecosystem models include: length, weight, condition, and age of individuals by sex [Rowe and Hutchings, 2003] as well as life-history data [Ward et al., 2016]. This data can then be integrated into ecosystem models to evaluate current and future trends. Potential models include biomass-based models like EwE (Ecopath-with-Ecosim) and end-to-end models like Atlantis which include spatially explicit food web interactions.

Individual variation can be included within EwE by adjusting key parameters to reflect individual variation. EwE models allow for variation and thus individual differences can be incorporated by allowing for population variation. For example, individual variation can be incorporated into diet matrices by adjusting prey-abundances. This in turn reflects the impact of individual differences on bottom-up ecosystem cascades.

In Atlantis, however, individual variation can be directly input into the model via "super particles". Thus, specific differences among individuals in regards to maturity, or size, or ontogenic shifts can be a parameter within the model.

When incorporating individual characteristics, especially differences in mating systems, the area considered within the FMU should be considered. For example, from an ecological scope perspective, the spawning grounds should be included, and from a temporal scope perspective, the timing of spawning should be considered. Excluding part of the spawning area from the FMU and in turn the model can have long-term implications on population estimation.

2 Habitat Considerations

2.1 Learning Objectives

2.1.1 Details

Learning Objectives 2

- Describe habitat characteristics that are essential to fish and explain how they can be incorporated into an EAFM framework
- Define MPA, explain their role, and explain how they can be incorporated into an EAFM framework

2.2 Essential Fish Habitat (EFH)

- Definition of habitat
- Important habitat components

2.2.1 Details

Definition 2: Habitat

The environment in which an organism lives including everything that is needed for the organisms survival, i.e. shelter, water quality, associated species (prey and otherswise), spawning grounds, etc..

From a fisheries management perspective essential fish habitat (EFH) refers to the water and substrates needed by fish for spawning, breeding, feeding and growth. Thus, the EFH for a particular species includes its prey, conditions required for spawning (i.e. substrate type, cover requirements, etc.), breeding (i.e. mate density, substrate type, cover requirements, etc.), and environmental conditions (water pH, DO requirements, nutrient content, etc.). Thus, habitat components are ecosystem level components whose impacts occur at the individual or population level.

When managing habitats it is important to look not only at the essential habitat components but also the interaction of these components. Specifically, the structure, function, and complexity of the environment needs to be considered along with the entities themselves. For example, some flatfish require a specific substrate composition in which the size composition of the substrate is more important than the presence of a rocky substrate Kaiser et al. [2003]. Remember, habitat complexity is an artifact of surface topography and internal structure of the substratum as well as the sessile epifauna which grow on it Kaiser et al. [2003].

When looking to include habitat components into an EAFM assessment several key components need to be considered:

- Habitat features of importance
- Habitat complexity preferences
- Impact of fishing gear on the habitat
- Proposed changes in the habitat from habitat management projects

2.3 Habitat Components

- Identify important habitat components
- Explain the role/importance of each habitat component

2.3.1 Details

the habitat components of the most importance to one species may not matter at all to another species. Similarly, compositional preferences for a particular habitat characteristic will vary among species. For example, tropical tuna such as skipjack, bigeye, and yellowfin are known to prefer warmer water temperatures than temperate tuna (albacore, Atlantic Bluefin, southern bluefin). However, even within tropical tuna small scale preferences emerge such that yellowfin prefer the highest water temperate, greater than 25°C, while bigeye and skipjack prefer temperatures ranging between 20 and 28°C [Arrizabalaga et al., 2015].

Although there is much variation in the actual conditions preferred by a particular species the following habitat components tend to be important predictors of where fish are found:

- Sea Surface Temperature (SST)
- Sea Surface Salinity (SSS)
- Sea Surface Height (SSH)
- Dissolved Oxygen (DO)
- Chlorophyll a (Chl a) and Chl a derived primary production
- Mesoscale Oceanographic Features (fronts, eddies, and filaments)

Sea Surface Temperature

Definition 3: Sea Surface Temperature (SST)

Sea surface temperature refers to the water temperature in the top 10 μm - 5m, depending on the type of instrument being used.

Why Include SST

Fish, unlike mammalian species, are unable to self-regulate body temperature. Therefore, as SST increases or decreases in temperature so does their internal temperature. As a result, small changes to SST can affect a fish's activity level (i.e. more active in warmer water), range (i.e. fish migrate to find optimal temperatures), metabolic rates (cellular activity increases as temperature increases), etc. Similarly, altering the water temperature can disturbed the chemical composition of the water. For example, warmer water does not hold as much dissolved oxygen (DO) as cold water. In fact, Munday et al. [2009] found that when water temperature in Australia's Great Barrier Reef exceeded the average summer temperature of 29°C by 3°C that aerobic activity of *Ostorhinchus doederlenine* decreased by 36% and that mortality rates increased sharply.

Sea Surface Salinity (SSS)

Definition 4: Sea Surface Salinity

Sea surface salinity is the amount, grams, of salt per 1000g of water.

Why Include SSS

Sea surface salinity is an important predictor of low level food sources such as plankton. Specifically, decreases in SSS have been linked to declines in plankton productivity Kaiho et al. [1996]. Decreasing plankton productivity could have cascading impacts on higher order fish, which are also typically the fish of commercial value. For example, Morita et al. [2001] found that North Pacific chum salmon (*Oncorhynchus keta*) decreased in size as SSS decreased. Morita et al. [2001] attributed the correlation to unfavorable feeding conditions created by decreases in plankton productivity.

Sea Surface Height (SSH)

Definition 5: Sea Surface Height (SSH)

"...the height of the ocean surface relative to a level of no motion defined by the geoid, a surface of constant geopotential..." Leben and Hausman [2016]

Why Include SSH
SSH is often considered an important habitat component within ecological models as it acts as a proxy for several oceanic features including tides, circulation patterns, and the distribution of heat and mass. Thus, SSH has been used to associate fish species with climatic events like *ElNiño* or *LaNiña* and oceanic upwellings which play an important role in nutrient movement and mixture.

Dissolved Oxygen(DO)

> **Definition 6: Dissolved Oxygen(DO)**
>
> The concentration of gaseous oxygen in the water.

Why Include DO
Fish, like humans, require oxygen for survival. However, unlike humans, fish acquire oxygen directly from the water through their gills. The amount of DO is a result of atmospheric O_2 absorbtion, photosynthesis, respiration, temperature, and salinity, to name a few. When the amount of DO drops below the critical threshold for a species its behavior, blood O_2 saturation, metabolic rates, ability to swim, egg and larval development, circulation, ventilation, gas exchange abilities, and resilience can be negatively affected [Davis, 1975]. These negative consequences can ultimately result in toxicity and in turn death for fish.

Chlorophyll *a* and Chlorophyll *a* derived primary production

> **Definition 7: Chlorophyll *a***
>
> The green pigment present in plants and cyanobacteria that is responsible for the absorption of light for photosynthesis.

Why Include Chlorophyll a
Chlorophyll *a* concentrations are included as a proxy for primary production. Primary production, as the base of the food web, ultimately determines the number of trophic levels a system can sustain as well as the number of individuals which can be sustained at each trophic level.

Chlorophyll *a* can also be an indicator for nutrient load. High levels of chlorophyll *a* can indicate high levels of total phosphorous and total nitrogen

[Søndergaard et al., 2011] which can result in cyanobacteria blooms which cause toxicity at high levels by reducing DO.

Mesoscale Oceanographic Features

Definition 8: Mesoscale Oceanographic Features

Mesoscale oceanographic features are oceanic features measured on the scale of 50-500km and 10-100 days.

Mesoscale oceanographic features of importance within an EAFM framework include fronts, eddies and filaments.

What are Fronts, Eddies, and Filaments

Definition 9: Mesoscale Oceanographic Fronts

Oceanic fronts are transitional areas between masses on the oceans surface which manifest themselves as horizontal gradients in temperature, salinity, density, turbidity, and color.

Definition 10: Mesoscale Oceanographic Eddies

Mesoscale oceanographic eddies are the "weather" of the ocean measured on a monthly timescale in an area less than 100km.

Definition 11: Mesoscale Oceanographic Filaments

Lines of strong oceanic surface convergence.

Why Include Mesoscale Oceanographic Fronts, Eddies, and Filaments
Mesoscale oceanographic fronts are associated with increased vertical and horizontal mixing resulting in increased primary and secondary production. Thus, they are often characterized by high phytoplankton biomass resulting in enhanced activity at higher trophic levels. Infact, Acha et al. [2004] found that frontal zones along the continental shelves of austral South America result in exceptionally large amounts of primary production, increased feeding

and/or reproductive habitat for nektonic species and act as retention areas for benthic species larvae.

Mesoscale oceanographic eddies play an important role in the transport of heat, salt, carbon, and nutrients across the ocean including transport within strong currents such as the Gulf Stream [CTOH, 2013]. Thus, these eddies are often associated with upwellings and increased productivity. Infact, Godø et al. [2012] found that eddies not only increase productivity leading to improved foraging grounds for fish and stimulate energy flow among trophic levels but also shape the distribution and density of marine life from the surface to the bathyal depths.

Filaments, unlike eddies, move water outwards. Thus, filaments also play an important transport function but in dispersion rather than concentration. This dispersion caused by filaments plays an important role in the movement of larval fish. Rodrıguez et al. [1999] found that in the waters between Northwest Africa and the Canary Islands that the distribution of neritic larvae was closely tied to the presence of filaments.

2.4 Marine Protected Areas (MPA)

- Definition of marine protected areas
- Role of MPA in fisheries management
- When MPA can be used to meet EAFM goals/objectives

2.4.1 Details

One of the primary habitat management techniques for oceanic fisheries is to create marine protected areas (MPA).

Definition 12: Marine Protected Areas (MPA)

"A clearly defined geographic space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" IUCN

MPAs come in several forms with varying degrees of protection and restriction. They are classified based on their conservation focus, level of protection, permanence, and constancy and scale of protection. As a result, MPAs vary in their "openness" from multiple use areas, which allow everything from fishing and snorkling to motorboats, to no access areas, which restrict all human access. The two most common MPAs within an EAFM framework are multiple-use MPAs and No-take MPAs (areas closed to all fishing activities for atleast part of the year). Although the application of MPAs varies widely their overall goal is ultimately the same, improve the natural and cultural heritage of the area.

Role of MPAs in Fisheries Management

MPAs allow for a way for fisheries mangers to prioritize areas of conservation interest and increase restrictions to achieve management objectives. According to Pomeroy et al. [2013], within an EAFM framework, MPAs are viewed as a suitable management objective whe

1. Controlling fishing mortality of sedentary species in data poor situations
2. Buffering against uncertainty
3. Managing for multispecies fisheries
4. Minimizing by-catch
5. Protecting habitat and biodiversity
6. Allocation/access to resources and reinforcement of user rights

When developing an MPA the size, location, and restrictions need to be taken into consideration within the context of the management goals and objectives. However, some general guidelines include:

- Size: large enough that some of the eggs and larvae they produce are retained within the MPA
  - This should be considered within the FMU
- Location: MPAs should try to incorporate 20-40% of each habitat [Green et al., 2013] and connectedness among MPAs to create corridors of movement

- Restrictions: should be set to maximize ecosystem improvements while minimizing socio-economic impacts

For more information on how to create MPAs see Green et al. [2013].

When MPAs should be used in EAFM

MPAs are often put into action in order to reduce or eliminate commercial fishing pressure. Typically, the reduction or elimination of commercial fishing is set to allow a particular stock and/or habitat to recover. However, this method does not address the root of the problem. Thus, other actions need to be taken along with the MPA to aid in the recovery and sustainability of the stock. Similarly, initiating a no-take or restricted-take MPA can negatively impact the livelihood of the fisherman and/or local communities which goes against the socio-economic considerations vital to EAFM. Thus, the use of MPAs needs to be strategic and well planned.

When done properly MPAs can be used to improve habitat conditions, stock recovery, as well as the fishery. Specifically, there tends to be more and larger fish within an MPA than outside it [?]. Similarly, recovered areas within MPAs tend to have higher biodiveristy than their surrounding area [?]. From a fishery perspective, the areas adjacent to MPAs have been known to benefit from the spillover effect, i.e. fish, larvae, and eggs from within the MPA migrate outside the MPA making them susceptible for fishing mortality. The spillover effect may benefit the adjacent fishery; however, from a management perspective it means that the areas surrounding an MPA need to monitored as well to ensure overfishing is not occuring and thus the stock as a whole cannot recover.

Case Study 2: Western Mediterranean MPAs

As of 2008, 94 MPAs occured within the Mediterranean Sea Gabrié et al. [2012]; however, the effectiveness and economic impact of these areas was not well understood. Thus, Goñi et al. [2008] investigated the impact of spillover from 6 of these MPAs. Each MPA included in the study had been functional for atleast 8 years, incorporated areas of fisheries closure and restricted use where fishing was allowed, and the stock of interest had recovered. Utilizing CPUE data Goñi et al. [2008] found that significant spillover occured and extended 700 to 2500m outside the fishery closure areas. Thus, MPAs were an effective way to recover fish stocks while not significantly negatively impacting the fisher in the long-term.

2.5 Incorporating Habitat into an EAFM Framework

- Types of habitat data
- EFH models
- Components to consider within a model

2.5.1 Details

As previously defined, an organisms habitat includes all of the necessary components for it to live and prosper within an area. Thus, if maintaining a sustainable stock is the management object than the fish's habitat must be managed to ensure its ability to spawn, breed, feed, and mature. Habitat considerations are incorporated within management models and management actions, such as designating MPAs, to ensure stock recovery and sustainability.

EFH Data and Models

From the habitat components described earlier in this lecture (SST, SSS, SSH, DO, Chl a, Chl a derived primary production, and mesoscale oceanographic features) one most select the habitat components which are of the most importance to the species of interest, i.e. they must determine the essential fish habitat components. To determine which habitat components are EFH components an EFH analysis can be conducted. The goal of EFH analyses are to isolate the habitat components/geographic areas of the most importance to the sustainability of a particular stock.

EFH analyses can be run using a wide variety of fisheries data including: acoustic data, trawl data, incthyoplankton data, egg data, and CPUE (catch per unit effort) data. EFH analyses can then use the fisheries data as response variables and the selected habitat data as the explanatory variables.

When selecting the explanatory, or habitat, variables to include within an EFH model it is important to consider the biology and ecology of the species. Thus, all data included in the model should be there because it represents an important component to the species life history. Other important considerations when selecting habitat components include:

- Multi-stock assemblages and habitat use
- Ensure the habitat definition is uniform and relevant within biological, physical-hydrographic, and ecological criteria
- Address spatial and temporal scales in uniform ways
- EFH changes across life stages for a particular species

To aid in the selection process several statistical models exist including AIC (Akaikie's information criteria) and BIC(Bayesian information criteria).

Once the EFH components have selected they can then be integrated with the fisheries data using GIS or similar software programs. Specifically, habitat data can be attached to specific sampling points. Thus, each fisheries data entry point will be linked to habitat data. From this information, the presence/strength of relevant ocean processes can be determined by calculating the distance between the process and the fish sampling point. The resultant information can be used to create FMUs and MPAs which are incorporated into the EAFM management plan.

For detailed information on modelling EFH see Valavanis et al. [2008].

3 Community Considerations

3.1 Learning Objectives

3.1.1 Details

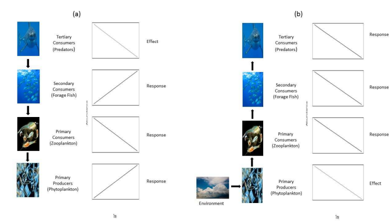
Learning Objectives 3

- Explain trophic cascades and why they should be included within an EAFM framework
- For each community model identify the type of data needed, be able to run the model, and interpret the model output
- Explain how community characteristics and community model out-

put can be incorporated into an EAFM framework

3.2 Role of Trophic Cascades in an Ecosystem

- What are trophic cascades
- Why they should be included in an EAFM framework
- Explain how fisheries impact trophic cascades



(a)top-down trophic cascade within a four-level food web (b) bottom-up trophic cascade within a four-level food web. Figure was adapted and modified from Curry et al. [2003].

3.2.1 Details

Trophic Cascades and Their Importance

When including community considerations into an EAFM framework managers are concerned with the interactions among living organisms, i.e. how abundance changes in one species impacts the abundance of another species. Community interactions typically result from predator-prey dynamics and occur in one of two directions: bottom-up or top-down. In bottom-up cascades, the abundance of the lowest trophic level is reduced, or increased, resulting in subsequent decreases in higher trophic levels due to decreased food. In top-down cascades, the top trophic level, say secondary consumers, decreases resulting in an increase in primary consumers (decreased predators), which causes a decreases in primary producers (increased predation). These interactions are collectively referred to as trophic cascades.

Definition 13: Trophic Cascade

The alteration of abundance, biomass, or productivity across trophic levels resulting from predator-prey interactions.

Trophic cascades play an important ecosystem role as they can have a significant impact on fish population dynamics and can even stabilize them in alternate states Curry et al. [2003]. Thus, trophic cascades can result

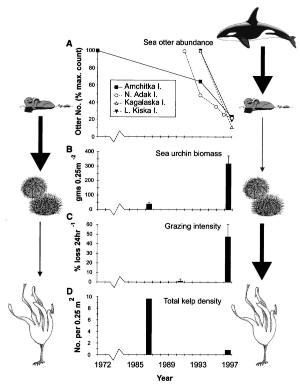


Figure 2: Trophic cascade present in Alaska's Aleutian archipelago: A) Changes in sea otter abundance across time (B) subsequent change in sea urchin biomass, (C) grazing intensity of sea urchins on kelp, and (D) kelp density. The error bars presented represent 1 SE. Dark arrows represent strong trophic interactions while light arrows represent weak interactions. This figure was redrawn from Estes et al. [1998].

in dramatic shifts in the appearance, properties, and functionality of the ecosystem. However, trophic cascades are fluid in that they exhibit variation in their strength and duration. As a result, for each ecosystem of interest, the community interactions within it must be well understood to fully express their impact on the ecosystem.

Fisheries and Trophic Cascades

Commercial fisheries often act as a driver for top-down trophic cascades. As previously discussed, commercial fisheries tend to disproportionately harvest large, top-predators reducing the abundance/biomass of the higher trophic levels. As a result, fisheries have begun focusing more on lower trophic levels in a phenomenon known as "fishing down marine food webs (FDFW)". FDFW is quite pervasive since high trophic levels tend to be K-selected species and are therefore more susceptible to overfishing.

3.3 Trophic Indicators

- What are trophic indicators
- Why are trophic indicators used
- Types of trophic indicators
- Calculating trophic level

3.3.1 Details

What are Trophic Indicators

To describe the complex nature of interspecies interactions a set of indicators, trophic indicators, is often created. Trophic indicators are mathmatical models used to simplify the complexity of these interactions so that managers can easily express community interactions to stakeholders when making management decisions. Ultimately trophic indicators provide information on the state of the ecosystem, the extent/intensity of fish mortality on the community and ecosystem as a whole, and provide benchmarks for measuring management progress [Pennino et al., 2011].

Types of Trophic Indicators

There are 3 major types of trophic indicators: marine trophic index (MTI), fishing in balance index (FiB), and Pelagic/demersal index (P/D). All three indices's can be calculated using the same data type, i.e. fishery landings, but focus on a slightly different relationships and therefore Pennino et al. [2011] recommends using all three congruently when making management decisions.

The three major trophic indicators will be explored in the following slides.

Calculating Trophic Level

The basis for all 3 trophic indicators is trophic level, or more specifically, identifing the dominant trophic levels and how energy moves amongst trophic levels. Thus, in order to calculate the trophic indicators one most first calculate, or obtain from the literature, the trophic level for individual species. Trophic level calculations are completed using dietary information. The calculation used to determine trophic level is

$$TL_i = 1 + \sum_j (TL_j \times DC_{ij})$$

where TL_j is the trophic level of prey species j and DC_{ij} is the fraction of prey species j in the diet of species i.

In marine ecosystems, the trophic level of most fish is between 2.0 and 5.0.

3.4 Trophic Interactions: Marine Trophic Index (MTI)

- What is the MTI
- Types of MTI (including cutMTI)
- How is the MTI calculated
- What the results indicate
- Pros/cons of the indicator
- $^c ut$MTI

3.4.1 Details

What is MTI and How is it Calculated

The marine trophic index (MTI) is a trophic indicator used to calculate the mean trophic level landed during a particular year. MTI is calculated on a yearly basis, i.e. each year of interest needs to be computed independently, and can be derived from a combination of fisheries landings and diet consumption data, used to determine trophic level. To compute MTI the following equation is used

$$MTI_K = \Sigma_i (TL_i)(Y_i) / \Sigma_i Y_i$$

where TL_i is the trophic level of group i and Y_i is the landings of trophic group i.

Interpreting MTI Results

When interpreting MTI output one is particularly concerned with the trend in MTI across time, i.e. is the MTI increasing, decreasing or stable. More specifically, one is concerned with the presence of a downward trend as it indicates an unsustainable fishery Pauly and Watson [2005]. If a downward trend is occurring than the community is shifting from predominately high trophic levels to lower trophic levels indicating that "fishing down the food web" is occurring.

Issues with MTI

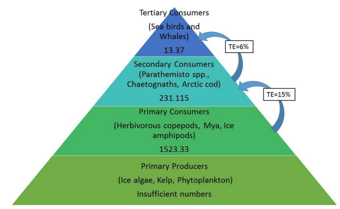
Although MTI does a good job of displaying trophic level shifts the interpretation is not always clear. Specifically, as mentioned earlier, a shift across time from high trophic levels to lower trophic levels typically results in the conclusion that FDFW is occurring, however, that is not always the case. Rather, a boom in lower trophic levels may be occurring from eutrophication. To eliminate this problem Pauly and Watson [2005] suggests placing a lower limit on the trophic levels included.

^{cut}MTI

^{cut} mean trophic index (^{cut}MTI) calculates the mean trophic level caught during a particular year but with a limit placed on the lowest trophic level included in the calculation. Typically a cut-off value of 3.25 is used, eliminating herbivores, detrivores, and planktivores from the calculation Pennino et al. [2011]. The elimination of herbivores, detrivores, and planktivores from the calculation is suggested because their biomass is heavily influenced from environmental factors rather than fishing pressure.

3.5 Trophic Interactions: Fishing in Balance (FiB)

- What is FiB
- How FiB is calculated
- What the results indicate
- Pros/cons of the indicator



Energy transfer in $kj \cdot m^{-2}yr^{-1}$ within the Lancaster Sound Region of Arctic Canada, data adapted from Welch et al. [1992].

3.5.1 Details

What is FiB and How is it Calculated

The fishing in balance index (FiB) addresses community dynamics by applying the law of 10%. The law of 10% states that on average only 10% of the energy available at one trophic level will be passed onto the next trophic level. The 90% energy loss is attributed to maintenance, reproduction, and other activities by the animals in the system.

FiB aims to capture the effect of intentionally fishing down, i.e. fishing a lower trophic level, has on the fisheries production. It is assumed that any decrease in mean trophic level should be matched by an ecologically appropriate increase in the same trophic level, i.e. the increase in catches should be proportional to the transfer efficiency, or how well energy moves, between trophic levels. To calculate FiB the following equation in used:

$$FiB_K = log[Y_K \times (1/TE)^{MTI_K}] - log[Y_0(1/TE)^{MTL_0}]$$

where K is the year, Y_K are the landings in year K, TE is the transfer efficiency (which is usually set to 0.1 to reflect the law of 10%), MTI_K is the mean trophic index in year K, and MTL_0 is the mean trophic level of landings in year 0 (year 0 can be any year used as a baseline).

Interpreting FiB Results

The number derived from the FiB index indicates whether the increase in landings from fishing a lower trophic level is proportional to the expected increase given the transfer efficiency between trophic levels. Thus, like the

MTI, one is concerned with the trend across time rather than the value itself. A stable FiB indicates that a proportional shift is occurring while a decrease may be indicative of an impaired fishery or unreported discards.

Pros/Cons of FiB

In order for FiB to function properly, it must be assumed that the transfer efficiency between trophic levels is constant across trophic levels. Similarly, the transfer efficiency must be known. Given the assumptions, FiB is believed to be a better indicator of ecosystem change than catch or catch composition as a result of its integrative nature.

3.6 Trophic Interactions: Pelagic/Demersal Index (P/D)

- What is the P/D index
- How it is calculated
- What the results indicate
- Pros/cons of the indicator

3.6.1 Details

What is P/D and How is it Calculated

The pelagic/demersal index (P/D) is a biological, rather than diet, index looking at community change from a large trophic group perspective. The large trophic groups incorporated into the model can include planktivorous, benthivorous, or piscivorous fish. The index can be run using production, consumption, biomass, or catch data and is calculated by taking the ratio of pelagic fish relative to demersal fish [Cury et al., 2005]. For example, a P/D ratio can be computed by calculating the change in the biomass ratio across time for pelagic piscivorous fish compared to demersal piscivorous fish. Or, to categorize ecosystem changes, the biomass ratio between piscivorous and planktivorous fish can be determined.

Interpretting P/D Results

The trend in P/D across time provides an indication of ecological changes across time as well as impact of the fishery. For example, when looking at the impact of a fishery, it would be expected that the P/D ratio shows a proportional decrease in piscivorous fish. While a relative increase in pelagic fish can be indicative of eutrophication, as they tend to be positively influenced by plankton production and demersal fish tend to rely on benthic communities which are negatively impacted by eutrophication[Pennino et al., 2011].

Pros/Cons of P/D

P/D indices are a useful way of quantifying ecosystem level changes in data-poor situations [Pennino and Bellido, 2012]. Specifically, the P/D index allows for a synethesises of the structure and function of an ecosystem across time and space using commercial statistics. Through the P/D index, managers are able to observe the impact of fisheries and eutrophication. However, deciphering the driving force behind the ecosystem changes, i.e. is it fisheries or eutrophication, is often difficult.

3.7 Incorporating Community Considerations into an EAFM Framework

- How to select which interactions to include
- How to include community considerations into EAFM's management objectives

3.7.1 Details

Because each trophic index describes a slightly different component of the community Pennino et al. [2011] recommends utilizing all 3 indices when drawing conclusions. That is, by using all three indexes the trends within the ecosystems become more apparent.

The primary use of trophic indicies within an EAFM framework is to compare the observed trends to management benchmarks such as reference points. However, due to the sheer complexity of the ecosystems involved, it is crucial that reference points and indices are not compared across ecosystems.

But rather, the benchmarks/reference points are created for each specific ecosystem of interest.

4 Climatic Considerations

4.1 Learning Objectives

4.1.1 Details

Learning Objectives 4

- Define GCC and ocean acidification and explain how they impact fish habitat and the ecosystem as a whole
- Explain why GCC and ocean acidfication should be included in an EAFM framework
- Explain how GCC and ocean acidification can be incorporated into an EAFM framework

4.2 Global Climate Change (GCC) and Ocean Acidification

- Define GCC and ocean acidification
- Explain the general relationship between GCC and fisheries
- Explain the general relationship between ocean acidification and fisheries

4.2.1 Details

What are Global Climate Change and Ocean Acidification

Definition 14: Global Climate Change (GCC)

Global climate change (GCC) is the long-term change in the Earth's climate.

Definition 15: Ocean Acidification (OA)

Ocean acidification is the reduction in the ocean's pH from the absorption of CO_2.

In both GCC and OA the proximate cause is an increase in atmospheric greenhouse gasses, CO_2 especially. The increase in atmospheric greenhouse gases drives the climatic changes observed in GCC. Similarly, the ocean is the largest absorber of atmospheric CO_2; as atmospheric CO_2 increases the world's ocean's absorb more CO_2. The absorption of CO_2 increases the water's acidity by increasing the amount of biocarbonate ions. The increased formation of bicarbonate ions alters the amount and bonding formation of hydrogen ions which reduces the amount calcium carbonate produced, which plays an important role in the ecosystem.

For more information on GCC see Mcmichael et al. [2004]. For more information on OA see Doney et al. [2009].

GCC and Fisheries

The climatic impacts of GCC are projected to have significant impacts on the world's fisheries. However, the impacts will vary depending on location, among other things. For example, in the western Pacific, the increased atmospheric and in turn water temperature is increasing stratification in the water column. The increased stratification is expected to reduce the amount of nutrient-rich water reaching the photic zone which would decrease primary production. While in the the Indian Ocean, where air and water temperatures are cooler, reduced stratification is expected to occur and cause increases in primary production. As a result, we will talk in general terms rather than specifics.

On a global scale, GCC is causing:

- an increase in average global temperature (1-3 $°C$ above 1990 levels)
- an increase in average sea surface temperature (0.6 $°C$ rise over the last 100 years)
- altered precipitation patterns
- more frequent and intense hurricanes and other storms

- increased sea level height (3.3±0.4mm/year between 1993-2006, 0.5-1.2m by 2100)
- decrease sea surface salinity

The changes associated with GCC will impact organisms directly via increased SST, for example, and indirectly by altering their habitat and food webs.

Impact of Increased SST
Increases in SST are expected to impact the physiological condition, growth rate, reproductive capabilities, and behavior of fishes. From a growth and physiological perspective, increased water temperature would increase metabolic rates while food availability is expected to decrease from reduced primary production. Thus, fish are expected to be of lower physiological condition and smaller. Similarly, the development, transmission, and susceptibility to disease increases as temperatures increase. Increasing disease prevalence tends to result in decreased reproduction and fish size and can increase the frequency and intensity of die-offs.

Reproduction rates are also expected to decrease as a direct result of increased SST. Specifically, most fish species are only capable of reproducing within a small temperature range. Thus, if the SST exceeds their tolerance range reproduction would be inhibited.

Behaviorally speaking, increases in water temperature can affect predator-prey interactions. Because fish have higher metabolic demands in warmer waters their need to forage increases making them more susceptible to predators. Also, the reduction in available food may cause them to forage in a larger area exposing them to more predators.

As a result, fish, especially temperature sensitive species and those living at the edge of the temperature tolerance, are expected to shift their ranges to more "acceptable" regions. Range shifts will in turn alter fish community dynamics including food-webs.

OA and Fisheries

Much like the impacts of GCC, the effects of OA occur directly and indirectly. However, whether a species is impacted directly or indirectly tends to relate to the type of species.

Impact on Invertebrates and Other Calcifying Species
Invertebrates and other marine organisms which rely only calcified shells will be directly impacted by OA through altered chemical composition reducing their ability to calcify. Specifically, calcifying species need carbonate to produce their calcified shells; however, when the ocean absorbs CO_2 the chemical reactions in the water are altered and carbonic acid is formed which in turn makes bicarbonate, carbonate, and hydrogen ions. The hydrogen ions then attach the carbonate making it unavailable to shellfish and invertebrates. The reduction in calcification causes slower shell growth, decreased shell strength,and decreased development and survival by the young. Thus, large population decreases are expected.

Impact on Fishes
Fishes, unlike marine species which calcify, tend to be more impacted by the environmental changes than the elevated CO_2 levels themselves. For examples, corals provide crucial habitat complexity and structure in much of the worlds reefs. However, corals are dying off because the carbonate saturation levels of the ocean are decreasing. The reduced carbonate saturation impairs corals ability to create their skeletons and if the saturation levels drop too low the water can actually dissolve their existing skeletons. Thus, declining coral populations reduce the amount of habitat available for reef fish.

Increased CO_2 has also been known to directly impact fish via behavioral changes. Fish that are exposed to high levels of CO_2 experience impaired sensory function which affects their habitat selection and predator avoidance capabilities.

Further reading

Much of the information presented here was adapted from Heenan et al. [2015].

4.3 Climatic/Habitat Components to Consider

- Identify habitat components to consider in relation to GCC/ocean acidification

4.3.1 Details

Incorporation of the climatic and habitat components is initially done through a risk assessment and then a vulnerability assessment.

Definition 16: Risk Assessment

Risk assessments evaluate which climatic components, or associated habitat changes, pose the greatest risk.

Definition 17: Vulnerability Assessment

Vulnerability assessments evaluate how at risk a particular species/community is to climatic/habitat changes of the greatest concern.

Therefore, risk assessments and vulnerability assessments are used to identify the climatic factors most important to the system of interest as well as identify how sensitive species would be impacted by the changes Gaichas et al. [2016]. Thus, the climatic components included within EAFM will vary by region depending on the results of a risk assessment. However, several habitat/climate components are typically included:

- Sea surface temperature (SST)
- Primary production
- Sea level rise
- Sea surface salinity (SSS)
- Currents
- Biogeochemistry of the ocean

The expected changes of these components from GCC and OA as well as their associated ecosystem impacts will be discussed in the next lecture.

4.4 Ecosystem Responses to Climatic Change

- Explain potential ecosystem responses from GCC
- Explain potential ecosystem responses from ocean acidification

4.4.1 Details

As previously mentioned, several habitat/climatic components need to be explored when assessing the impact of GCC and OA on an ecosystem. The components include:

- Sea surface temperature (SST)
- Primary production
- Wind and Currents
- Biogeochemistry of the ocean

Ecosystem Impacts of GCC

Sea Surface Temperature (SST)
As previously mentioned, the rising atmospheric temperature resulting from GCC have caused an average SST increase of $0.6°C$ over the past 100 years. The rising ocean temperatures can significantly impact life history characteristics, population growth, and ecosystem processes.

Rising ocean temperatures significantly impact the biological processes of oceanic organisms including enzyme reactions, diffusion, and membrane transport. More specifically, as temperature increases the rate at which enzymes fire increases resulting in increases in metabolic rates which in turn impact the functioning of an individual, population, and community. Thus, as temperatures rise and metabolic rates are shifted, communities are expected to see changes in their food-webs. Infact, increases in temperature have been shown ot reduce total food web biomass as well as the plant to animal ratio.

Increases in SST can also shift community dynamics by altering the growth of species. For example, poikilotherms increase as temperature increases whereas fish at the edge of their temperature tolerance decrease in biomass as they migrate out of the system. As a result population connectivity, local adaptation, and speciation can be impacted.

Rising sea surface temperatures can also impact the ecosystem via alien species including disease. Increased temperatures have been associated with pathogen and vector range expansion. The introduction of new diseases along with the increased stress from environmental changes increases an individuals susceptibility. As a result, increases in disease prevalence are often associated with increases in SST.

Warmer ocean temperatures also impact the ocean's stratification. As ocean temperatures warm stratification increases reducing mixing which reduces nutrient availability and perpetuates the decrease in primary production. The increased stratification and temperature are also expected to decrease dissolved oxygen concentrations leading to further declines in primary production.

Primary Production

Primary production globally has decreased by at least 6% since the 1980s. However, the decline in primary production is not evenly distributed - most of the decline, 70%, has occurred at higher latitudes. The declines in primary production negatively impact food web dynamics.

As SST increases primary production biomass decreases. The decrease is a result of decreased production from reduced nutrient availability, see above, and increased predation due to increased metabolism of herbivores. However, increased predation appears to have a larger impact than production because respiration is more sensitive than photosynthesis to changes in temperature.

Primary production is also negatively impacted by the reduction in sea ice. In northern latitudes, spring ice melt plays an important role in the timing of phytoplankton blooms. As sea ice becomes less abundant the timing of phytoplankton blooms will be altered as well as the potential extinction of sea-ice algae. Declining sea-ice algae has been associated with a $75 \pm 21\%$ decrease in krill which is a primary food source for many marine organisms.

Wind and Currents

The increased wind and altered behavior of currents associated with GCC are expected to significantly influence the distribution and abundance of marine organisms.

Increasing wind strength is expected to intensify upwellings and increase the amount of organic material entering deeper shelf waters. Increasing the amount of organic material in deep shelf waters could lead to increased respiration, hypoxia, and toxic gases such as methane and hydrogen sulfide being released from deep anoxic sediments. The consumption of oxygen and release of toxins is expected to result in large die-offs of deep-water benthic communities.

Similarly, uneven oceanic heat distribution is projected to alter the behavior of oceanic currents. Specifically, the strength and direction of oceanic currents are expected to shift as temperatures continue to rise. Shifting currents will further alter heat distribution and nutrient movement.

Further Reading
Much of the information in this section was adapted from Hoegh-Guldberg and Bruno [2010].

Ecosystems Impacts of OA

Biogeochemistry
As previously discussed, oceanic waters absorb CO_2 from the atmosphere. Thus, as atmospheric CO_2 increases the amount of CO_2 absorbed by the ocean also increases. The increased concentration of oceanic CO_2 has resulted in the acidification of the ocean's surface layer. Infact, the pH of the ocean has decreased by 0.02pH units per decade over that last 30 years for a total decrease of 0.1pH units since pre-industrialization.

The increase in ocean acidity results in substantial declines in carbonate ions. The decline in carbonate ions is a result of increased hydrogen ions which alter the typical bonding patterns. As a result, the saturation state of calcium carbonate is lowered which can cause dissolution for calcifying species if their shells/skeletons are not protected.

As a result of the biogeochemical changes calcifying species such as plankton, corals, coralline algae, and many other invertebrates, are more likely to experience reduced shell thickness, fertilization rates, developmental rates, and larval size. Declines or loss of these species can have significant ecological impacts.

Corals are especially susceptible to changes in calcium carbonate saturation. As saturation levels decrease their ability to formulate skeletons decrease and at extremely low saturation levels dissolution occurs. This is especially important from an ecosystem perspective as corals are an important habitat component for many organisms. Corals form complex structures and produce calcium carbonate. Thus, a reduction in coral means a further decline in calcium carbonate as well as habitat loss. Benthic invertebrates are also expected to decline as a result of decrease ability to calcify. Reductions in benthic invertebrates such as bivalves can compound water quality issues as they are important water purifiers.

As a whole, a slow down in calcification is expected to

- Reduce calcifying species ability to compete with noncalcifying species
- Reduce the age at which calcifying species are sexually mature
- Alter buoyancy
- Alter light behavior in the water column
- Reduce habitat complexity
- Increase pollution levels present in the water
- Shift food webs
- Alter species distributions

Further Reading
Much of the information in this section was adapted from Doney et al. [2009].

4.5 Incorporating Climatic Considerations into an EAFM Framework

- How to integrate GCC and OA into EAFM

4.5.1 Details

Integrating GCC and OA into EAFM

Integrating climate change and ocean acidification into EAFM needs to be carried out throughout the planning, execution, and re-evalution processes. To properly include GCC and OA and their associated impacts, their impacts need to be carefully distinguished from consequences of other environmental stressors. Once their specific impacts are isolated they can be worked into the 5 steps of EAFM.

Step 1: Define the Scope of the FMU
When determining the geographic size of the FMU, fisheries management unit, the current and future distribution of target species needs to be considered. Specifically, the increased water temperature, changes in food web dynamics, and alterations to mating systems associated with GCC are likely to alter the distribution and range of species. As a result, it is important

that the FMU cover all grounds where the species of interest currently exist and where they are projected to exist given the best known scientific data.

Once an FMU is designated it is important that the FMU allow for adaptative management. As the chemistry of the water changes the distribution and projected distribution of target species is likely to change. As these changes occur it is important that the FMU change along with it.

As is true for all stages of EAFM planning, it is important that stakeholders be included within the FMU planning. Designating and altering the FMU can provide important opportunities for managers to explain changes as well as educate stakeholders on the potential impacts of GCC and OA. This is also an opportunity for stakeholders to inform managers of their observations.

Step 2: Identify and Prioritize Issues and Goals

In order to identify and prioritize issues a metric needs to be created to evaluate which components are the most important. To accomplish this vulnerability and risk assessments are completed. As previously defined, vulnerability assessments are a tool to determine how at risk a particular species is to the projected climatic/habitat changes. Whereas risk assessments determine which climatic/habitat components are of the highest priority. Thus, risk assessments are typically run to identify the climatic/habitat components to include within a vulnerability assessment. Given the results of the risk assessment and associated vulnerability assessment long-term management goals can be written which try to negate the negative impacts of GCC and OA on species/habitats of greatest concern.

Step 3: Develop and EAFM Plan

Within the management plan itself the list of long-term management goals created in Step 2 should be included. The inclusion of these management goals ensures that the issues associated with GCC and OA will be addressed. It is also important to look at other management goals and objectives through a GCC lense, i.e. how will GCC impact our ability to meet a particular goal.

Steps 4 and 5: Implementation, Monitoring, Evaluation and Adaptation of the Plan

Due to the uncertainty associated with GCC and OA it is important that the EAFM management plan be re-evaluated frequently. In order to do this effectively, data needs to be collected on a regular basis and analyzed. Any new findings and their associated management changes should be addressed with stakeholder groups prior to implementation to maintain transparency

Further Reading

Much of the information presented here was adapted from Heenan et al. [2015].

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