Loss of *Saccharina sessilis* in Deadman's Bay
An assessment of an algal regime shift in the northeast Pacific

Sean Dougherty[1]

FHL 470 Historical Marine Ecology Research Experience
Spring 2018

[1]Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250

Contact information:
Sean Dougherty
8501 Wallingford Ave. N. #2
Seattle, WA 98103
seanydoc@gmail.com

Keywords: *Saccharina sessilis*, turf algae, canopy algae, Deadman's Bay

Abstract
Shifts in subtidal, intertidal, and reef algal communities are occurring worldwide. The trend has been an increase in filamentous turf algae and a decrease in ecosystem engineering canopy algae and has been attributed to both rising sea surface temperature and increased coastal eutrophication. On San Juan Island, WA, *Saccharina sessilis* is among the most prominent species of canopy forming algae. Declines of *Saccharina* have been observed on the west coast of the island in Deadman's Bay. Loss of canopy species is correlated with a decrease in encrusting coralline algae and an increase in filamentous turf and articulated coralline algae. Here we quantify the change in algal composition of the rocky intertidal at Deadman's Bay by comparing contemporary abundance data with a 1973 student research project from the University of Washington's Friday Harbor Laboratories. Decreases of 7.03% average percent cover of canopy species and 8.72% of encrusting corallines were reported. Increases of 3.85% and 3.68% average percent cover of filamentous turf algae and articulated corallines, respectively, were also found. Temperature data from nearby weather stations shows an increase in both sea surface and air temperature over the 45-year period since the original study was conducted. Canopy forming kelp species are susceptible to warming sea surface temperatures and the data collected here will be useful in monitoring a change in community composition on San Juan Island.

Introduction

Canopy algae are important in intertidal ecosystems and are referred to as ecosystem engineers (Christie et al. 2009). They provide shade and create habitat for a diversity of animals and other algae (Feldman 1937). Globally, canopy algal species, especially kelp, are vanishing and being replaced by various turf algae (Fillbee-Dexter 2018). Turf algae are a group of diverse macroalgae that share morphological and ecological similarities (Connell et al. 2014). In contrast to the canopy algae, turfs create very little three-dimensional structure and instead carpet the substratum with a dense layer of fine filaments or branches. These algae tend to be small, fast growing, and opportunistic species with relatively high turnover rates and stress tolerance compared to large fleshy macroalgae (Airoldi 1998). Turf algal morphology makes them trap and accumulate sediments, which alters the chemical environment of their surroundings. The transition of ecosystems to flat, mat-like turfs is undesirable and associated with losses of habitat and food for fish and invertebrates as well as declines in overall primary productivity (Airoldi et al. 2007, Connell et al. 2014).

The reduction in canopy algae is often associated with a predictable shift in understory algae. The effects of canopy algae are often strong and morphological groups of understory taxa have been identified based on their association with the canopy (Whitmore 1989). The specific mechanisms that alter the assemblage of understory algae involve numerous physical factors affected by canopies such as light intensity, sedimentation, and water flow (Connell 2003, Duggins et al. 1994). The combination of enhanced light and sedimentation conditions in the absence of canopy algae facilitates an increase in cover of erect algal species that trap sediments into their structure (turfs and articulated corallines). Conversely, reduced light and sedimentation under canopy species promotes greater coverage of encrusting coralline algae (Connell 2005). Therefore, a shift from canopies to turfs can be examined by carefully observing the assemblage of understory algae in addition to the presence and abundance of the canopy species themselves.

Drivers of algal regime shifts from canopies to turfs can be difficult to separate. Potential impetus includes abiotic (ocean warming, eutrophication) and biotic (herbivory, epiphytism) factors (Fillbee-Dexter 2018). While it is an arduous task to identify the primary mechanism behind the shift, human activities have certainly played a large role. In the northeastern Atlantic Ocean, filamentous turf algae have replaced canopies of *Saccharina latissima* and kelp abundance has declined as much as 80%. The reduction has been attributed to a combination of warming sea surface temperatures over five decades and coastal eutrophication (Moy et al. 2012). This change in environmental conditions favors rapidly growing filamentous algae, including kelp epiphytes. The effect was most severe in shallow, protected areas where temperatures are higher and wave action is unable to keep epiphytes from proliferating (Fillbee-Dexter 2018). Obviously, abiotic and biotic factors are integrative in their influence on abundance and distribution of organisms in any ecosystem. In this study, the effect of increasing temperature on canopy algae abundance is examined.

Deadman's Bay is on the west coast of San Juan Island, WA, United States. Intertidal canopy algae in this region have not been studied extensively compared to those in the Atlantic. Students from the University of Washington Friday Harbor Laboratories sampled a zone of the rocky intertidal in this bay in 1973 and calculated relative abundance of algal species present at that time. The canopy algae *Saccharina sessilis* (formerly *Hedophyllum sessile*, hereafter *Saccharina*) was abundant, accounting for almost 20% of the algal cover (Dwinell et al. 1973). The results of this survey have created a unique opportunity to observe the ecological response of a northeast Pacific rocky shore to 45 years of warming. This site is protected from wave action and therefore more susceptible to the effects of warming (Fillbee-Dexter 2018). Furthermore, this area of beach and the adjacent land became a preserve in 1995, presumably reducing direct anthropogenic effects of harvesting and pollution. The fact that kelp canopy algae are highly sensitive to anthropogenic disturbance (Bellan-Santini 1968, Benedetti-Cecchi 2001) confounds difficulty in determining the primary mechanisms behind their decline. The geography of the site and the establishment of the preserve enhance insight into the drivers of change by reducing the signal from the direct anthropogenic influences of pollution and harvesting and enabling the contemporary study to focus on the effects of warming. The rise in sea surface temperature is positively correlated to turf algae abundance and negatively correlated to canopy algae abundance along coastlines worldwide. In Deadman's Bay the decline of the canopy algae *Saccharina sessilis* in the intertidal is being observed. Here we repeated a survey of the flora and fauna of this site to determine and quantify the changes over the past 45 years. Temperature increase, as determined by data from a nearby weather station, was compared to the change in abundance of *Saccharina* and various species of turf algae. Additionally, these changes were examined in relation to the abundance of understory algal species.

Methods

Site information

Deadman's Bay is just south of Limekiln State Park on the west coast of San Juan Island, WA. This location faces Haro Strait and is more exposed to wind and waves than sites on the eastern side of the island. Nevertheless, compared to the outer coast, this bay is greatly protected and minimal wave action is observed. The area was established as a preserve in 1995 when the citizens of San Juan Island purchased the property through the San Juan County Lank Bank with assistance from the Trust for Public Land and Washington State Recreation and Conservation Funding Board (San Juan County Parks). The preserve encompasses nearly 500 m of shoreline, including the rocky outcrop in the north of the bay that was resurveyed (Fig. 1). The preserve also contains 16 adjacent acres of forest, coastal prairie, and wetland.

***Figure 1 The study area on Deadman's Bay on the west coast of San Juan Island, WA.* The 1973 student survey included a sketch of the rocky outcrop in the north of the bay that was sampled. Here the sketch is overlain on a Google Earth image from April 2017.**

The rocky shore in the bay is a large mass of igneous rock measuring 114m along shore from north to south. An abrupt cliff rises from the water in the north, establishing the northern bound of the study area and a steeply sloped rocky beach establishes the southern limit (Dwinell et al. 1973). This temperate rocky shore is littered with tide pools and channels that are scattered throughout. Topography of the study area lacks uniformity; however, when considering the complete space, the irregularity is consistent. Thus, a random sample of the intertidal provides an accurate depiction of the abundance and zonation of the organisms living in Deadman's Bay.

Surveys

Students from Friday Harbor Laboratories conducted a survey of Deadman's Bay in the spring of 1973. Their goal was to report the relative abundance of algae and invertebrates as well as illustrate the zonation of the intertidal taxa. Contemporary surveys were conducted 4-5 and 16-18 May 2018, coinciding with projected negative tides. The historical data were derived from surveys in April and May 1973. Exact surveying dates and the number of assessments in the original study were not specified but seasonal differences were avoided by sampling in the same month. Sea surface and air temperature from the Friday Harbor weather station for this time period were included in the historical study. An air temperature time series was compiled using data from the Olga 2 SE, WA, US station accessed via NOAA's National Climatic Data Center, https://www.ncdc.noaa.gov/cdo-web/.

Sampling technique

The survey of the rocky shore at Deadman's Bay was randomly distributed across the entire study area. A base transect was laid from north to south, parallel to the beach of the study area. The original survey considered the low tide line to be 0 m and placed six transects from the low tide line to the beach. The modern survey differed slightly from the historical; 4 transects were used instead of 6. Also, the first 2 transects were sampled using the historical methodology; i.e., the transect measurements started at the low tide line and increased toward the beach. The final 2 transects were measured from the highest of the splash zone, down to the low tide line. The methodology was changed for efficiency and ease of measuring, and to ensure the transect was not moved by wave action as the tide came in. A random number generator was used to determine distances along the beach transect where the six sample transects would end or start (again, the first two measured from the low tide to the beach transect, the final two measured from the beach to the low tide). Precise locations of transects from the historical survey were not available, but they were randomly distributed in the contemporary study so the results are miscible. Using Google Earth®, lines were drawn from the sample transect end/start points, perpendicular to the beach transect, out across the study area (Fig. 2). The historical data had a maximum length of 46 m from low tide to the highest quadrat sampled, therefore, the digital sample transects were drawn 55 m from the beach transect to ensure the line would encompass the whole intertidal of the study area. The greatest length from low tide to the highest of the splash zone was 51 m in the modern study.

Figure 2 Sample transects distributed randomly across the study area running perpendicular to the beach. **The base transect running parallel to the beach measured 114 m. Ten 0.25 m^2 quadrats were randomly placed along each perpendicular transect. GPS locations of the quadrats are available in the supplementary table.**

Following the placement of the sample transects, ten 0.25 m^2 quadrats were placed on each transect. Quadrats were placed directly on top of transects, per the historical survey. It should be noted that the 1973 researchers counted 20 quadrats on the first of the sample transects, but then decided this was an inefficient and unnecessary methodology and placed only 10 on the remainder. A random number generator determined how far from the low tide line, or from the base transect, to place the quadrats. Transects inevitably covered different distances of the intertidal as a result of the geography of the study area. If the generated distance placed the quadrat above the splash zone or below the low tide line on a particular transect, it was not included in our survey and the next randomly generated location was used instead. In the historical survey, any quadrat location that was generated more than once was counted twice when calculating relative abundance; however, the current research team did not repeat quadrats and moved on to the next randomly-generated location, in order to maximize the overall quadrats sampled. The actual coordinates of the 40 quadrats sampled were determined in the field using a Garmin eTrex®10 handheld GPS (Supplemental Table).

Algae were recorded as percentage cover of a 50 cm by 50 cm quadrat, divided into 25 sub-quadrats measuring 10 cm by 10 cm each. Scores from 0 to 4% were assigned to each taxon in each sub-quadrat after visual inspection. Final percentage cover of each quadrat was obtained by adding the 25 sub-quadrats. This method has been shown to be an effective way of obtaining accurate percent cover (Dethier 1993). Invertebrates were counted by individual animal and reported as such. Canopy algae, where present, were accounted for and then moved aside to expose the understory, thus algal percentage of single quadrats may exceed 100%. This technique was preserved from the historical methodology.

Analysis

Individual species were recorded in the field and then categorized into morphological groups for analysis (Table 1). Turf algae are commonly referred to but rarely well defined in publications (Connell 2014). Here we considered turfs to be dense, filamentous algae with thalli that grow on average to a length of < 15 cm. Average percent cover of the 40 quadrats was calculated as well as relative abundance of the various species and groups of algae.

Morphological Group	Articulated coralline	Crustose coralline	Other (non-calcifying) crusts	Filamentous turfs	Other filaments	Canopy	Foliose
Species	*Bossiela sp., Calliarthron regenerans*	*Lithothamni-on sp.*	*Ralfisa sp. Petrocelis, Hildenbrandia sp.*	*Acrosiphonia coalita, Antithamnionella pacifica, Encocladia muricata, Polysiphonia collinsii, Pterosiphonia bipinnata,*	*Desmarestia viridis, Odonthalia floccosa*	*Saccharina sessilis, Fucus distichus, Egregia menziesii, Alaria marginata, Sargassum muticum*	*Mazzaella splendens, Hymanena sp. Wildemania norrisii, Pyropia sp. Ulva sp.*

Table 1 Morphological groups of algae found at Deadman's Bay. **Some species were only found in the historical survey, others only in the contemporary.**

Results

Canopy algae have decreased in abundance in Deadman's Bay by an average of 7.029% (Fig. 3). *Saccharina sessilis* is less abundant in 2018 (0.65% average percent cover) than it was in 1973 (8.71% average percent cover) (Fig. 4). The percent cover of encrusting corallines has also decreased (11.75% in 1973 compared to 3.03% in 2018). Filamentous turf algae have increased in abundance, accounting for 6.14% historically and 9.99% in 2018. Finally, articulated corallines have increased from 1.35% in 1973 to 5.03% in 2018.

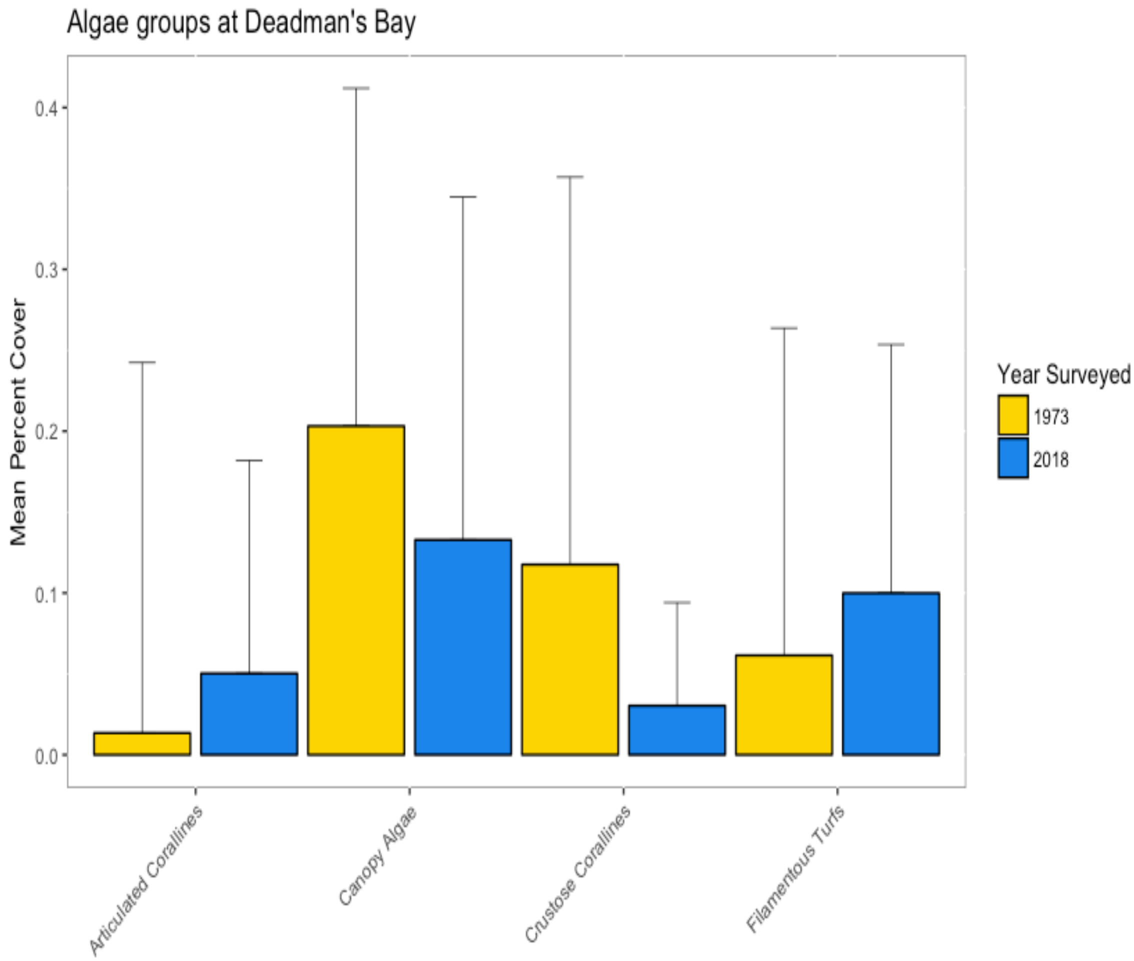

Figure 3 Average percent coverage of morphological groups of algae at Deadman's Bay in 1973 and 2018. **Decreases in abundance of canopy and crustose coralline algae and increases of articulated coralline and filamentous turf algae were observed.**

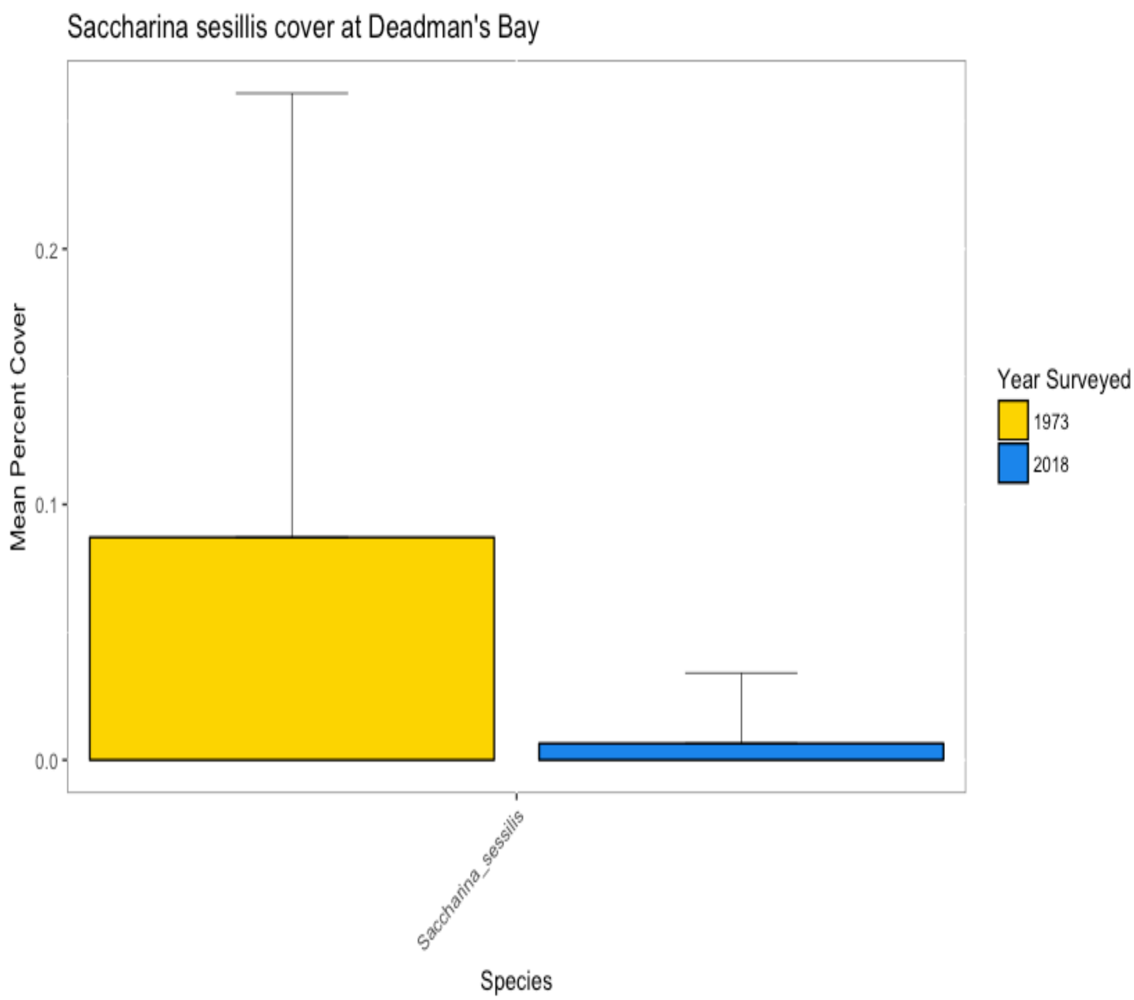

Figure 4 Decrease in the abundance of the canopy forming alga Saccharina sessilis from 1973 to 2018 at Deadman's Bay.

Air temperature has increased almost 1˚C in the San Juan Islands over the 50-year period from 1966-2016(Fig. 5) and sea surface temperature in the Haro Strait has also increased 1˚C in this time period (Fields 2018). The air temperature data used was from an Orcas Island weather station with the longest running dataset available through NOAA's National Climatic Data Center. The sea surface temperature was from Race Rocks Ecological Reserve, British Columbia, Canada. This marine protected area is located 37 km from Deadman's Bay, on the west side of the Haro Strait.

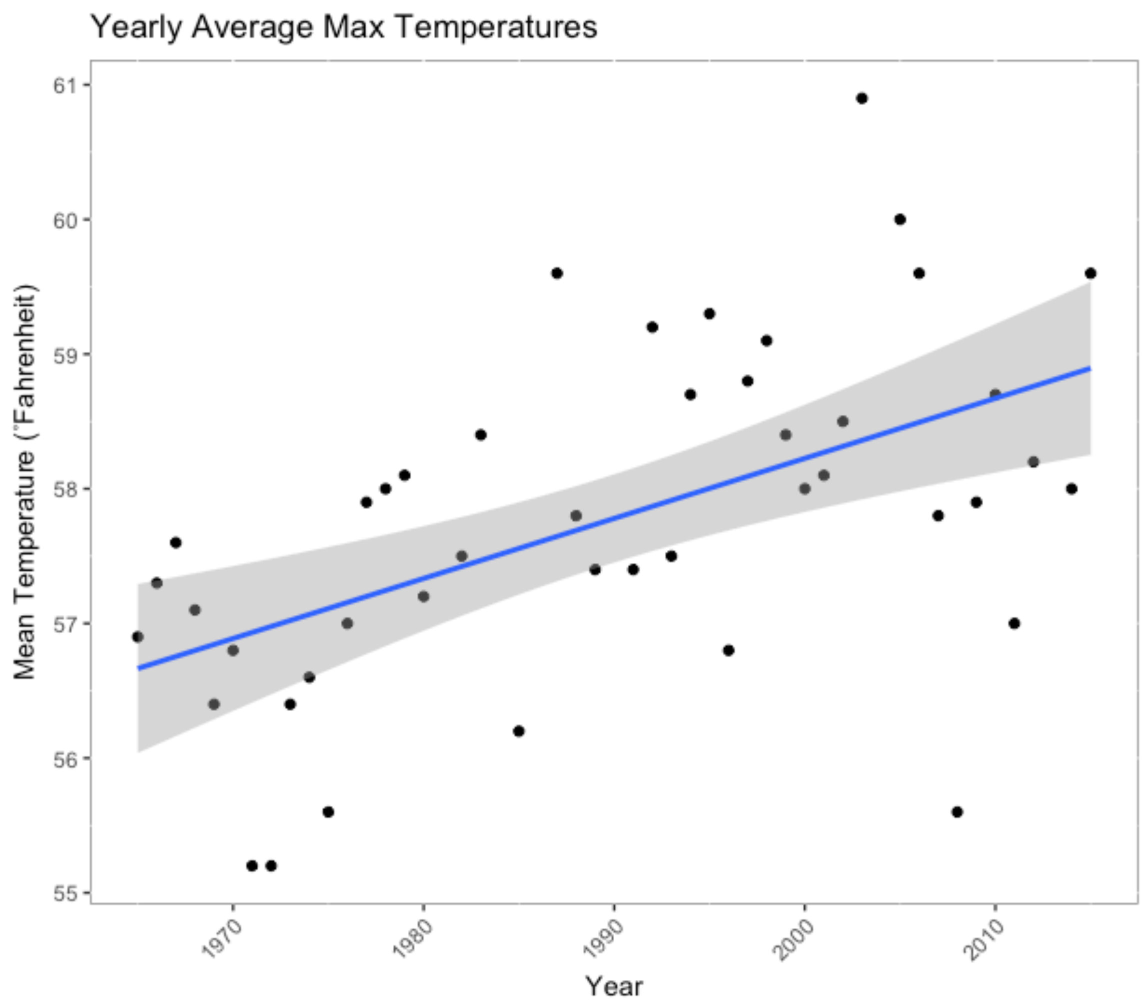

Figure 5 An increase in mean maximum air temperature at Olga weather station on Orcas Island, WA, US. **Data from NOAA's National Climate Data Center accessed via https://www.ncdc.noaa.gov/cdo-web/.**

Discussion

This survey suggests that the rocky shore at Deadman's Bay is losing canopy cover and predictable changes in understory algal assemblage are occurring. The decrease in *Saccharina sessilis* is dramatic; however, the fucoid, *Fucus distichus* has increased in abundance. This is likely related to the biogeography of the study area. Peaks and valleys exist throughout the intertidal and some areas close to the low tide line had large tidal heights and were completely covered in *F. distichus* which typically thrives in the higher intertidal. The rockweed, *F. distichus*, has been shown to increase photosynthesis at higher temperatures (Colvard et al. 2014). The photosynthetic potential of the sea cabbage, *S. sessilis*, decreases with increasing temperature (Lamote et al. 2012, Nguyen et al. 2014). The antithetical responses of these two canopy forming species were not equal and the overall effect was decrease in canopy cover.

The decrease in canopy algae is positively correlated with a decrease in encrusting coralline algae. In the original 1973 survey, *Lithothamion sp.* and *Saccharina sessilis* were the two most abundant species found and the contemporary data suggest that they are both in decline. The decrease in the average percent cover of canopy algae and crustose coralline algae are of similar magnitudes. The canopy provides shade and inhibits sedimentation, creating an environment in which the coralline crusts can thrive (Irving 2006). The observed decline in *Lithothamnion sp.* is therefore likely due to the increased light and sedimentation reaching the substratum in the absence of canopy algae.

The results show an increase in both filamentous turf algae and articulate coralline algae. These types of algae grow quickly and opportunistically in areas of high light and sedimentation and their observed increases were of similar magnitude. They are able to incorporate sediment into their thalli (Connell 2005) and often alter the chemical environment of their immediate surroundings. This may be of increased importance in the rocky intertidal at Deadman's Bay, where turf algae may modify the chemical composition of the many small tide pools.

The observed increase in temperature and turf algae and decrease in canopy algae suggest a shift toward turfs may be occurring at Deadman's Bay on San Juan Island's west coast. The degree to which the temperature increase is driving this shift should be evaluated further. Future work in the area should incorporate the interactions of canopy species and grazers, primarily *Katharina tunicata*, which was abundant under the canopy of *S. sessilis* during the 2018 re-census.

The emersion times of the various zones of the study site should be quantified. The heterogeneity of the area causes some portions of the intertidal to be exposed to air much longer than others. This means the algae growing on one rock may be more subject to desiccation than algae growing on another rock adjacent to it. Naturally, the success of intertidal algae is highly tied to the risk of desiccation and therefore emersion times likely have a large impact on the community composition. Increased temperature and emersion time will likely reinforce the effects of one another, as algae exposed to higher temperature air for longer periods will be more damaged than if the temperature were lower. Taken in conjunction, the 1973 and 2018 algae abundance data should be integral in creating a baseline for this ecosystem which may be used to evaluate the efficacy of the protected status of Deadman's Bay and to assess anthropogenic effects on the rocky intertidal.

References

Airoldi, L. (1998) Roles of disturbance, sediment stress, and substratum retention on spatial dominance in algal turf. *Ecology,* **79,** 2759-2770.

Airoldi, L. & Beck, M. W. (2007) Loss, status and trends for coastal marine habitats of Europe. *Oceanography and Marine Biology, Vol 45,* **45,** 345-405.

Bellan-Santini, D. (1968) Conclusions of a quantitative survey on biocenosis of photophilous seaweeds in Mediterranean Sea on coast of Provence (France). *Marine Biology,* **1,** 250-256.

Benedetti-Cecchi, L., Pannacciulli, F., Bulleri, F., Moschella, P. S., Airoldi, L., Relini, G. & Cinelli, F. (2001) Predicting the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. *Marine Ecology Progress Series,* **214,** 137-150.

Christie, H., Norderhaug, K. M. & Fredriksen, S. (2009) Macrophytes as habitat for fauna. *Marine Ecology Progress Series,* **396,** 221-233.

Colvard, N. B., E. Carrington, & B. Helmuth. (2014) Temperature-dependent photosynthesis in the intertidal alga *Fucus gardneri* and sensitivity to ongoing climate change. *Journal of Experimental Marine Biology and Ecology*, **458**, 6-12.

Connell, S. D. (2003) The monopolization of understorey habitat by subtidal encrusting coralline algae: a test of the combined effects of canopy-mediated light and sedimentation. *Marine Biology*, **142**, 1065-1071.

Connell, S. D., & B. D. Russell. (2010) The direct effects of increasing CO2 and temperature on non-calcifying organisms: increasing the potential for phase shifts in kelp forests. *Proceedings of the Royal Society B-Biological Sciences*, **277**, 1409-1415.

Connell, S. D., B. D. Russell, % A. D. Irving. (2011) Can strong consumer and producer effects be reconciled to better forecast 'catastrophic' phase-shifts in marine ecosystems? *Journal of Experimental Marine Biology and Ecology*, **400**, 296-301.

Connell, S. D., Foster, M. S. & Airoldi, L. (2014) What are algal turfs? Towards a better description of turfs. *Marine Ecology Progress Series,* **495,** 299-307.

"Deadman Bay Preserve, San Juan Island." *San Juan County Land Bank*, Blooming Mind Media, 10 Mar. 2014, sjclandbank.org/deadman-bay-san-juan-island/.

Denny, M. W. & Paine, R. T. (1998) Celestial mechanics, sea-level changes, and intertidal ecology. *Biological Bulletin,* **194,** 108-115.

Dethier, M. N., Graham, E. S., Cohen, S. & Tear, L. M. (1993) Visual versus random-point percent cover estimations - objective is not always better. *Marine Ecology Progress Series,* **96,** 93-100.

Duggins, D. O., & J. E. Eckman. (1994) The role of kelp detritus in the growth of benthic suspension feeders in an understory kelp forest. Journal of *Experimental Marine Biology and Ecology*, **176**, 53-68.

Feldmann, J. (1937) Recherches sur la végétation marine de la Méditerranée. La Côte des Albères: première these, Wolf, *Rouen.*

Fields, Jamie Andersen. (2018) Temperature correlated changes in relative abundance of mollusks at Dead Man's Bay, San Juan Island, Washington. Unpublished, Friday Harbor Labs Student Papers.

Filbee-Dexter, K. & Wernberg, T. (2018) Rise of turfs: A new battlefront for globally declining kelp forests. *Bioscience,* **68,** 64-76.

Fowler-Walker, M. J., & S. D. Connell. (2007) Habitat heterogeneity as a consequence of sub stratum-orientation and kelp-canopy: Relating interdependent responses to common patterns. *Journal of Experimental Marine Biology and Ecology*, 343, 127-137.

Fowler-Walker, M. J., B. M. Gillanders, S. D. Connell, & A. D. Irving. (2005) Patterns of association between canopy-morphology and understorey assemblages across temperate Australia. *Estuarine Coastal and Shelf Science*, **63**, 133-141.

Irving, A., M. J. Fowler-Walker, & S. Connell. (2003) Associations of forest-type with morphology of *Ecklonia radiata* and abundance of understorey algae. *Transactions of the Royal Society of South Australia*, **127**, 167-175.

Irving, A. D., & S. D. Connell. (2006) Predicting understorey structure from the presence and composition of canopies: an assembly rule for marine algae. *Oecologi*a, **148**, 491-502.

Lamote, M., L. E. Johnson, & Y. Lemoine. (2012) Photosynthetic responses of an intertidal alga to emersion: The interplay of intertidal height and meteorological conditions. *Journal of Experimental Marine Biology and Ecology*, **428**, 16-23.

Moy, F. E. & Christie, H. (2012) Large-scale shift from sugar kelp (Saccharina latissima) to ephemeral algae along the south and west coast of Norway. *Marine Biology Research,* **8,** 309-321.

Nguyen, T. T., S. Y. Henderson, & J. L. Burnaford. (2014) Effects of low tide conditions on the photosynthetic health of the kelp Saccharina sessilis. *Integrative and Comparative Biology*, **54**, E323-E323.