Master's thesis

Methods for monitoring juvenile fish in variable coastal habitats

The effect of a bridge construction on gadoid numbers in Mjóifjörður, Iceland

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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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January 6th, 2010

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Abstract

In order to better aid in the development of integrated coastal management in the Westfjords, Iceland, a case study testing methods of juvenile fish sampling in shallow coastal areas and examining the effects of a bridge construction in Mjóifjörður on movement of gadoid fish were investigated during the fall months of 2009. Three different types of habitats: sand and gravel, maerl and kelp were sampled using gill nets as well as a baited camera system. Sampling took place in Mjóifjörður and in two of the surrounding un-impacted fjords. The abundance of juvenile Atlantic cod, *Gadus morhua*, as well as other gadoid fish and the by-catch were recorded from each method. Overall the results show a very low abundance of juvenile gadoids throughout the sampling area, and the previously un-tested baited camera system showed comparable results to the traditional sampling method of using gill nets in two of the three habitats investigated. Juvenile gadoid fish exhibited no differences in abundance between the fjords indicating no decrease in the movement of juveniles in the bridged fjord. Such information should aid in the decision making process regarding the management of such coastal engineering projects.

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1. Introduction

As the world population continues to increase, the pressures exerted on our coastal resources will also continue as our coastal zones are disproportionately accommodating most of the global population increases (Rahmstorf & Richardson, 2009). There is wide recognition of the need for better resource management worldwide. A popular solution that is being awarded great attention all over the globe is through the integration of management decisions in order to facilitate better involvement and minimize the exclusion of often under-represented but equally important stakeholders (Cicin-Sain & Knecht, 1998). Integrated coastal and marine management is a concept that has been adopted for our efforts to manage our marine and coastal resources and can be found in use throughout the world. In order to successfully integrate multiple uses of marine resources, a clear understanding of the natural ecology and how it is impacted by human activities is required. Therefore understanding the environmental impacts posed by human development is crucial for successfully integrated coastal and marine resource management (Rahmstorf & Richardson, 2009). Marine fisheries are often negatively affected by certain anthropogenic impacts. The management and protection of commercial marine fisheries is often complicated by different life stages of the species occupying different habitats as well as the complex food chain that each species belongs to and is frequently not very well understood (Jennings, et al., 2001). There is an urgent need for increased understanding of the consequences of our actions on sensitive life stages and habitats of many commercial species of marine fish.

In the case of Atlantic cod and gadoid fish in general the available data on the ecology of the benthic juvenile life stage is disproportional to the extensive knowledge on the larvae and adult stage (Begg & Marteinsdottir, 2002; Jonasson, et al., 2009). This is in part explained by the difficulty in applying standard sampling methods throughout the variable habitats utilized by juveniles and partly because important habitats are commonly in shallow waters, making them inaccessible to large research vessels (Stoner, et al., 2008). In Iceland, coastal waters have been shown to serve as important habitats for juvenile Atlantic cod and other gadoids (Jonasson, et al., 2009). A bridge together with its associated fill roads has been constructed across the fjord, Mjóifjörður in the Westfjords region of Iceland (figure 1). This has an impact on the hydrologic properties of the respective fjord, which in turn might have a negative impact on how demersal juvenile Atlantic cod and other gadoid fish enter and settle in the fjord.

The aim of the current study is twofold. 1) To develop and test methods for sampling and monitoring juvenile gadoid fish in a variety of habitats, focusing on shallow coastal waters. 2) To use these methods to estimate if the construction of a bridge across Mjóifjörður has an effect on the number of juvenile gadoids in the fjord.

2. Theoretical Framework and Case Study Introduction

Alterations to coastal habitats can have a great effect on the survival and recruitment of marine fish (Lotze, et al., 2006). In a study performed by Lotze, et al., (2006) historical trends in habitat alterations were examined to determine the drivers of degradation for commercial fish species of various economic importance, including tuna, sharks, diadromous fish such as salmon and sturgeon, demersal fish such as cod and halibut, and pelagic fish such as herring and sardines. The study examined the relative abundance of species over time and across different cultural periods in human history. The aims of the study were to provide "detailed historical baselines and quantitative targets for ecosystem-based management" (Lotze, et al., 2006, p. 1806). The findings show that degraded habitats and species abundance declines were directly related to exploitation and habitat loss in the majority of the worldwide cases examined (Lotze, et al., 2006). Controlling, preventing, and restoring degraded habitats is a central priority in coastal management.

Negative changes to coastal ecosystems and habitat degradation can result from a variety of anthropogenic activities. Any changes in the hydrologic makeup of a system can result in increased turbidity, eutrophication, changes in salinity and dissolved oxygen (Justic, et al., 1995; Richter, et al., 1996) all leading to negative impacts to the ecosystem (Griffiths, 1999; Layman, et al., 2007; Meager & Utne-Palm, 2008). Hydrologic alterations to coastal waters refer to any physical modifications to the entrance of a bay or changes in the shoreline that can influence natural processes, such as flow of water direction and/or volume (OzCoasts, 2009). As pointed out by Pringle (2003) “management and policy decisions regarding land-use activities and hydropower development are often made in the absence of adequate information on hydrologic connectivity” (Pringle, 2003, p. 2685). In her study Pringle introduces the concept of hydrologic connectivity and explains that our current knowledge of how this connectivity relates to the natural ecosystem is very poorly understood while it is often responsible for “dramatic losses in global aquatic biodiversity” (Pringle, 2003). While the impacts that hydrologic alterations have on the natural ecosystem have been well documented for freshwater environments as well as migratory salmonid species, there is a need for interdisciplinary research regarding land-use for many other marine fish and their respective habitats (Pringle, 2003). An extensive literature search has found no studies pertaining to coastal alterations within fjords in Iceland and their effects on marine fishes.

Layman, et al (2007) examined the effects of habitat alterations on the resiliency of a top predator, the grey snapper, in the Bahamas. The study adds to the existing body of research that establish a link between species diversity and hydrologic connectivity (Fahrig, 2003; Valentine-Rose, et al., 2007; Beach, 2002). Habitat fragmentation is evaluated by Layman based on the reduction in tidal amplitude of a shallow body of water before and after unspecified human alterations have taken place. Generally, shallow areas are prone to human induced impacts because of their proximity to human habitations (Beck, et al., 2001) and changes in the normal tidal flow affect the existing hydrologic connectivity of a system and impacting proper matter transport (Pringle, 2003). Sampling by Layman is undertaken with the use of many traditional methods including nets and traps, all individual species are recorded and graphed to show “niche dimensions” or food web complexity (Layman, et al., 2007). The results of the study show no differences between the severity of habitat alterations and the average size of fish, but species diversity is found to be reduced by more than 90% in the heavily impacted habitats (Layman, et al., 2007). The strengths of this study lies in the many methods used to sample the species composition and significant results that show the widespread phenomenon of niche depletion of a top predator by human induced alterations. By sampling the entire species composition in addition to the targeted species, the study undertaken by Layman helps move towards more integrated management solutions by understanding the entire functions of species within the food web and not just focusing on single species abundance measurements (Beach, 2002., Layman, et al., 2007).

Atlantic cod, *Gadus morhua*, is a demersal gadoid fish distributed throughout the North Atlantic (U.S. Department of Commerce, 2004). The first few stages of the Atlantic cod life are part of a pelagic phase. The eggs of Atlantic cod drift with the dominating currents to nursery areas (Juanes, 2007; Brickman, et al., 2007); eventually at sizes varying from 3.3 mm to 5.7 mm the larvae hatch (U.S. Department of Commerce, 2004). As size increases, transformation to the juvenile form occurs at lengths greater than 20 mm or 2-3 months from hatching (Fahay, 1983; Bolz & Lough, 1988). The juveniles take on a demersal life at lengths varying from 4 to 6 cm (Lough, et al., 1989). At this stage juvenile cod undergo a shift in diet from pelagic prey to benthic (Lomond, et al., 1998). Once juvenile cod have settled for a demersal life it has been shown that they actively select substrates with different particle size or macroalgae cover (Keats, et al., 1987) often according to food availability and predator interaction (Borg, et al., 1997; Gotceitas, et al., 1995). While most of the scientific work focuses on recruitment and adult carrying capacity (Ratz & Lloret, 2003; Marteinsdottir & Begg, 2002; Marshall, et al., 1998), relatively little attention has been given to localized processes that might affect the juvenile life stages of marine fishes (Lindholm, et al., 1999), especially compared to freshwater studies (Meager & Utne-Palm, 2008; Pringle, 2003). The available studies demonstrate that there is a direct connection between juvenile fish, their survival and specific substrate complexity (Auster, et al., 1995; Tupper & Boutilier, 1995; Stal, et al., 2008), hinting that recruitment might revolve around the completeness of the seafloor habitat (Lindholm, et al., 1999). In the Atlantic cod lifecycle there is a general shift from a broad and simple pelagic habitat to a narrower but more complex shallow benthic habitat before a return to a more expansive deep benthic environment as the fish mature (Juanes, 2007).

Coastal waters are important for the juvenile cod; they offer protection against predators and maintain food availability (Stal, et al., 2008). Studying the abundance and distribution of juvenile marine fishes in different habitats can be difficult because of traditional surveying methods such as trawling and seining will not provide an un-biased and un-destructive method of sampling in all habitats. In depth ecological studies on gadoid juveniles and studies in other systems that have comparable problems with sampling i.e. coral reefs, have often relied on scuba divers to directly observe and count fish (Tupper & Boutilier, 1995). Stoner, et al., (2007) studied the efficacy of a baited camera system as an alternative to trawling in surveying age-0 gadoids in the Pacific. The study also attempted to determine the appropriate deployment type of such a system and whether the baited camera system matched abundance estimates of a traditional sampling method, the beach seine. The species examined were: Pacific cod, saffron cod, and walleye Pollock. The experimental camera system consisted of a bait bag loaded with whole Pacific sardine placed 68cm in front of an underwater camera mounted on a metal sled which was lowered in shallow coastal waters around Kodiak Island, Alaska, USA (Stoner, et al., 2008). The assembly was kept submerged for periods of 20 to 40 min in three kinds of habitats: eelgrass, kelp, and bare sand/cobble. The results of the study show that the optimal time for abundance observation of Pacific gadoids was around 15 min (Stoner, et al., 2008) regardless of overall fish abundance and additional deployment time. The study also showed that the total number of fish seen in the view of the camera system was positively correlated with the beach seine sampling performed at the same site, authenticating the use of the method for gadoids in the Pacific. No similar studies examining the use of a non intrusive baited camera system compared to conventional sampling methods were found for the North Atlantic region, nor is there information regarding the optimal time of deployment of the bait bag for such abundance estimates. The study by Stoner, Laurel and Hurst (2008) detailed here explains the specifics of the baited camera system and offers the possibility of its use for other species in other parts of the world and other species.

In Iceland, after spawning, Atlantic cod eggs drift in a general clockwise direction within the country's coastal waters (Jonasson, et al., 2009). Larvae and pelagic juveniles are found throughout the fjords and bays around the country (Begg & Marteinsdottir, 2002), eventually the juveniles settle within the many habitats of shallow coastal waters found in the fjords. The numerous fjords comprising the Westfjords region of Iceland (figure 1) serve as such habitats for the juvenile demersal cod. The distribution and abundance of the larvae and pelagic stages of Atlantic cod have been examined by Jonasson, et al. (2009) in relation to variable environmental conditions. The larval drift route of west Iceland from the southwest spawning grounds to the nursery areas of the northwest were sampled over the course of several years with the use of a trawl. The study provided information on 2-8 week old individuals in respect to abundance, distribution as well as on various environmental factors such as temperature and salinity. The results show great variation in abundance between years, in the years 1998 to 2000 there was a high abundance of larvae and juveniles found in the low salinity waters of the Westfjords region, whereas in 2001 distribution was confined only to the Ísafjarðardjúp region (Jonasson, et al., 2009). The study found the highest abundance of Atlantic cod larvae and juveniles to be in the Westfjords region indicating the importance of the area as nursery grounds (Jonasson, et al., 2009). In relation to the available currents for the dispersal of pelagic juveniles the study concludes that "the role of the coastal current in successfully transporting larvae from the spawning areas into the northern nursery grounds is likely to be one of the main mechanisms influencing recruitment variability" (Jonasson, et al., 2009, p. 8). Although, there have been extensive studies on larvae and pelagic juvenile dispersal within the Icelandic waters (Jonasson, et al., 2009; Brickman, et al., 2007), and adult population abundance and spawning areas (Palsson & Thorsteinsson, 2003; Begg & Marteinsdottir, 2003), there is limited information regarding the shallow coastal habitat used by demersal juveniles in Iceland (Ólafsdóttir & Theodorou, 2008).

Bridges built across fjords are capable of alternating the natural ecology by changing the water velocity or turbidity within the fjord (Vatnaskil Consulting Engineers, 2002); possibly affecting both the resources available to the juvenile cod and their ability to feed and seek cover from predators. Specifically, a bridge recently constructed spanning across Mjóifjörður (figure 1), has significantly altered the hydrologic composition of the fjord (Vatnaskil Consulting Engineers, 2002). To date no data are available on the effects the bridge construction with its associated fill roads has on the juvenile cod and other gadoid fish. Lough, et al (1989) showed that water currents had significant effects on juvenile cod behavior; an increase in water currents required an increase in energy expenditure by the fish in order to orient themselves and swim against the currents. However, as the effect of the bridge in Mjóifjörður appears not to extend very far within the fjord the effects of the specific case examined in this study are expected to be limited to the possible restriction of juvenile movement into the fjord.

3. Materials and Methods

3.1.Study area

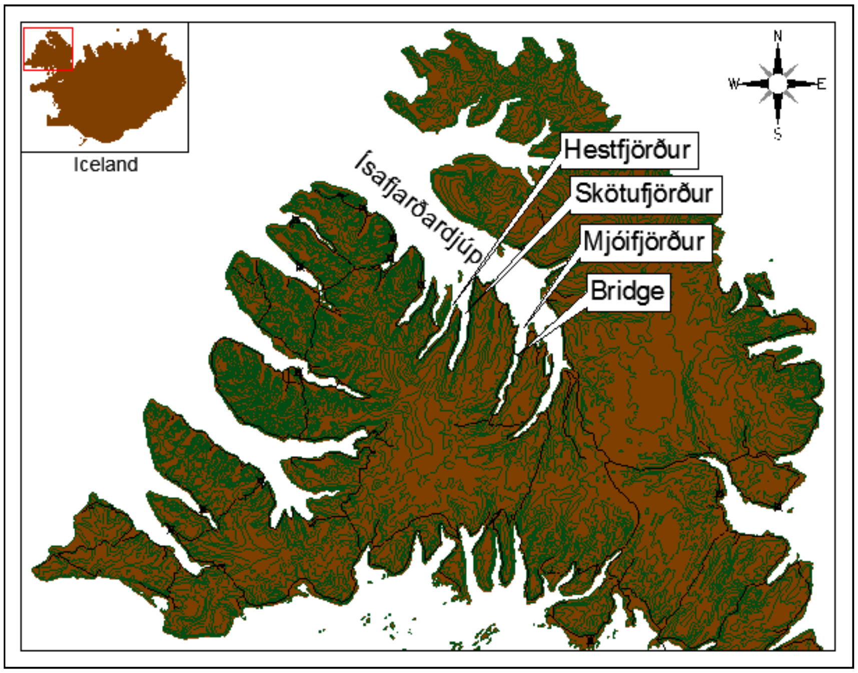

Figure 1. The Westfjords

In Mjóifjörður the construction of the bridge, completed in August 2009, is associated with fill roads that intrude into the fjord for over 500 meters, closing off a substantial area allowing water transport only through the opening created by the bridge. Due to the use of such engineering methods in Mjóifjörður, the tidal flows as well as possible larger dominating currents in Ísafjarðardjúp have increased dramatically underneath the bridge and have been virtually eliminated in the areas outlining the fill roads. A computer generated model performed by Vatnaskil Consulting Engineers (2002) shows hypothesized velocity vectors before and after the specified construction in Mjóifjörður (figures 2 and 3).

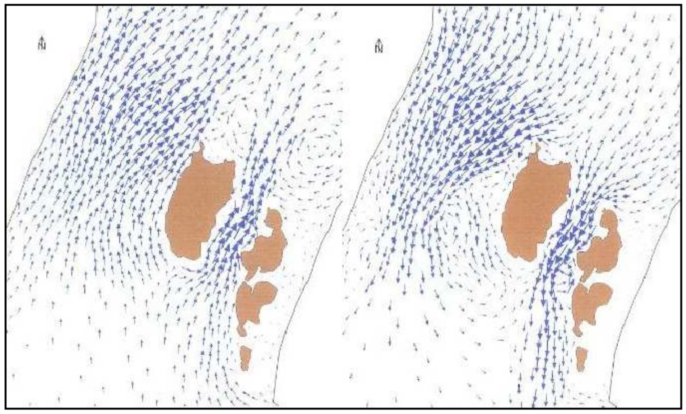

Figure 2a. Ebb tide Figure 2b. Flood tide

Figure 2. Velocity vectors of Mjóifjörður before bridge construction. (Vatnaskil Consulting Engineers, 2002).

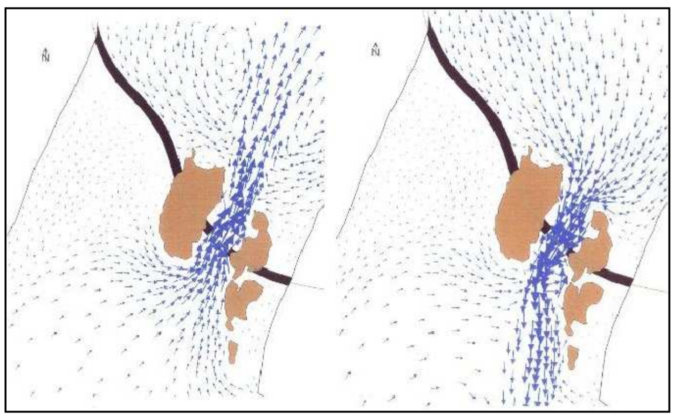

Figure 3a. Ebb tide Figure 3b. Flood tide

Figure 3. Velocity vectors of Mjóifjörður after bridge construction. (Vatnaskil Consulting Engineers, 2002).

The approximate length of fill road for Mjóifjörður is 750± meters with a 100± meter opening bridge span. Although only the shallowest areas have been closed by fill roads while the bridge was constructed over the deepest stretch to allow as much flow as possible during tidal events (figure 4), a substantial area of shallow habitat with normal daily tidal flows has been altered.

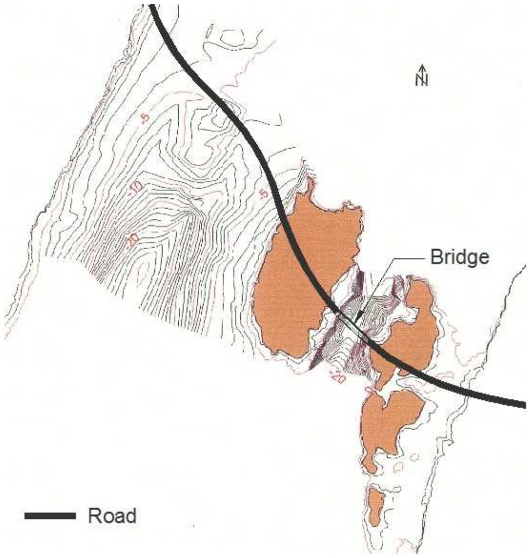

Figure 4. Bathymetry of Mjóifjörður surrounding the road and bridge construction. (Vatnaskil Consulting Engineers, 2002).

The Mjóifjörður fjord currently does not have any major residential or commercial developments within its watershed. The surrounding valleys support limited farming activities with little agricultural undertakings and a tourist resort offering lodging and amenities for approximately 20 to 30 individuals. The approximate watershed for Mjóifjörður is 174 km^2.

This paper describes the results of a series of studies conducted in three fjords in Ísafjarðardjúp: Hestfjörður, Skötufjörður, and Mjóifjörður (figure 1). The fjords are generally characterized by deep, mud substrate habitats with only limited areas at depths less than 20 meters. The shallower waters are characterized by three main types of habitats, kelp, *Laminaria spp.*, dominated, sand and gravel bottom and maerl dominated bottom. Maerl, *Lithothamnium spp.*, is a type of coralline red algae found in many fjords around Iceland (Eiríksson & Gunnarsson, 2002). Maerl beds serve as an important habitat for a diverse distribution of fauna (Birkett, Maggs, & Dring, 1998). The habitats were chosen using aerial photographs and visual surveys performed from small boats. All sampling took place within the months of October and November 2009.

3.2.Fish sampling

Two knotless nylon gill nets were laid at each sampling site. One 20 m long and 3 m high with 6.5mm stretched mesh, and the other 20 m long and 2 m high with 10mm stretched mesh. They were set at sites with depths ranging from 3±m to 20±m, and were deployed by the use of small inflatable boats. The nets were set together with approximately 100± m between them; they were deployed during the day and kept submerged for a duration of 24 hours, once at each site. This was repeated for each type of habitat once in Mjóifjörður and once in either Hestfjörður or Skötufjörður (figure 5). Catch per unit effort (CPUE) was recorded for all species on each haul. The fish were frozen and stored until standard length, and weight were analyzed in the laboratory. Numerous studies have researched the impacts of seriously degraded habitats on particular species by also focusing on the overall biodiversity index (Beach, 2002; Layman, et al., 2007) therefore for this study, all species caught using the gill nets are being presented to determine if there is a difference in species diversity among the fjords.

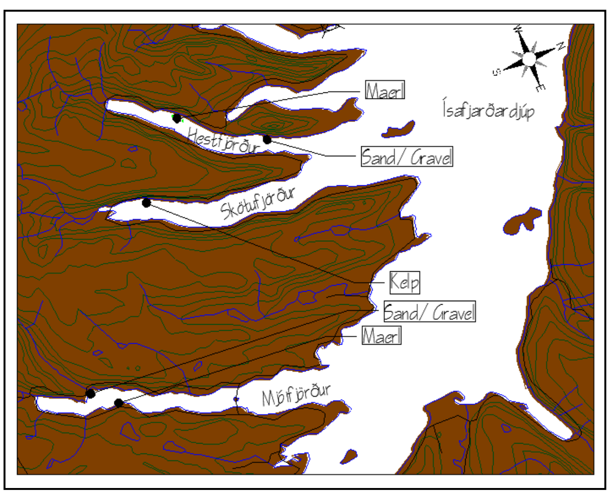

Figure 5. The sampling sites in Ísafjarðardjúp.

3.3.Estimating density with underwater cameras

The relative density of juvenile cod within each habitat was also estimated using a baited camera system. For a similar study pertaining to the efficacy of such methods see

Stoner, Laurel, & Hurst (2008). A series of time lapsed photographs were done with a camera mounted on a metal triangle and pointing at a bait bag consisting of cut herring pieces and shrimp (figure 6). Two random stations were chosen for sampling at each type of habitat. At each station the triangle was lowered on the sea floor and remained deployed for a period of 30 minutes, during which the camera was configured to take photographs every one minute. Additional measurements were performed using an underwater video camera. The video camera was likewise mounted on a metal triangle and set to point at a bait bag. Recordings were taken for 30 minutes continuously after which in the laboratory, screen shots at intervals of one minute were examined to determine fish count.

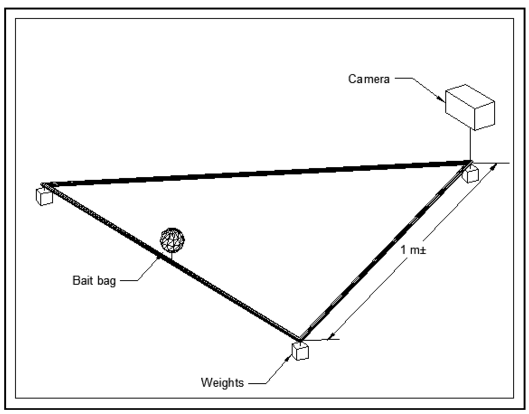

Figure 6. The baited camera system used in Ísafjarðardjúp.

3.4.Statistical analysis

Differences in occurrence of juvenile gadoids between fjords (bridge, no-bridge) and habitat type (sand/gravel, kelp, and maerl) were tested for significance using Kruskal-Wallis test. Differences in length of juvenile gadoids and other fish species caught in nets was estimated with ANOVA using fjord (bridge, no-bridge) and habitat type (sand/gravel, kelp, and maerl) as fixed factors. All statistical analyses were performed using SYSTAT release 12.

4. Results

4.1. Fish occurrence

A total of 106 finfish of 10 species were sampled with the gill nets at five sites. Juvenile gadoids were most abundant accounting for c.a. half the numbers, 54 juvenile gadoid fish thereof 29 Atlantic cod (*G. morhua*).

There was not a significant difference in the total number of fish, total number of gadoid juveniles nor number of cod juveniles caught in sand/gravel and maerl habitats in the un-impacted vs. impacted fjords (Chi-square=0.00, p-value=1.00, d.f.=1, n=2). As kelp substrate habitats were not found in the impacted fjord this could not be used for statistical comparison. Therefore the presence of juvenile cod is not significantly associated with the bridge construction in Mjóifjörður, where the un-impacted fjord did not appear to support a higher number of juvenile cod (table 1).

Table 1. Juvenile gadoid catch per unit effort in Hestfjörður, Skötufjörður, and Mjóifjörður, sampling carried out in Oct. and Nov. 2009.

Mesh size	*No bridge (Hestfjörður & Skötufjörður)*			*Bridge (Mjóifjörður)*		
	Sand/Gravel	Maerl	Kelp	Sand/Gravel	Maerl	Kelp
6.5 mm	1	0	1	0	0	x
10 mm	2	4	34	10	0	x

There was high variability in the number of fish between the kelp habitat and the other two habitats, sand/gravel and maerl (table 2). The kelp habitat appears to support more juvenile gadoids compared to habitats with little or no vegetative cover. However, the number of gadoid fish caught within the same fjord was not significantly related to the different bottom habitats, although this is most likely to represent the low statistical power of the sampling. In addition, a Shannon index comparison shows that the un-impacted fjords appear to support a higher diversity in species than the impacted fjord (table 2).

Table 2. Number of different species collected using gillnets at the five sample sites in Hestfjörður, Skötufjörður, and Mjóifjörður, sampling carried out in Oct. and Nov. 2009. Shannon index represents species diversity.

	Skötufjörður	**Hestfjörður**		**Mjóifjörður**	
	Kelp	**Sand/gravel**	**Maerl**	**Maerl**	**Sand/gravel**
Gadoid juveniles*	34	3	4	3	10
Sculpin					
Myoxochephalus scorpius	20	1	2	5	5
Urchin					
Strongylocentrotus droebachiensis	13		6	32	2
Spider Crab					
Hyas araneus		2	7	23	1
Starfish					
Asterias rubens	17	3	2	1	
Plaice					
Pleuronectes platessa	5	1		1	
Spotted snake blenny					
Leptoclinus maculatus		1	1	1	
Atlantic Herring					
Clupea harengus	1	4			
Sandeel					
Hyperoplus lanceolatus				1	1
Periwinkle					
Littorina spp.			1		
Jellyfish					
Schyphozoa		1			
Tortoisshell Limpet					
Acmaea testudinalis			1		
Hook-nose					
Agonus cataphractus				1	
Butterfish					
Pholis gunellus		1			
Brittlestar					
Ophiothrix			10		
Hermit crab					
Eupagurus pubescens			2		
Number of fish species	**5**	**6**	**4**	**6**	**4**
Total number of fish	**60**	**11**	**7**	**12**	**16**
Shannon index	**1,55**	**2,18**	**2,00**	**1,24**	**1,42**

* Gadoid juveniles consisted of: Atlantic cod, *Gadus morhua*, whiting, *Merlangius merlangus*, and pollock, *Pollachius virens.*

Juvenile cod occurrence as measured by camera observations was very low throughout the sampling areas (table 3).

Table 3. Juvenile gadoid occurrence in Hestfjörður and Skötufjörður, based on 30 minute camera estimates performed in Oct. and Nov. 2009.

	Sand/Gravel	Maerl	Kelp
Site 1	2	1	1
Site 2	0	0	0
Totals	2	1	1

4.2.Fish size

There was a significant effect of both habitat type and the fjord (Mjóifjörður vs. Hestfjörður and Skötufjörður) on the size of fish caught in gillnets (tables 4 &5, figures 7 & 8). The fish in un-impacted fjords were larger reflecting the higher prevalence of adult fish. In the case of juvenile gadoids only habitat type significantly explained variation in size, juveniles in sand/gravel habitats being slightly, but significantly, smaller (table 4). The same pattern was observed with weight and is not presented here.

Table 4. Results from ANOVA showing the effect of bridge and habitat type on juvenile gadoid size in Hestfjörður, Skötufjörður, and Mjóifjörður, Oct and Nov. 2009.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Bridge	18.092	1	18.092	0.172	0.680
Habitat type	1265.636	2	632.818	6.031	0.005
Error	5036.750	48	104.932		

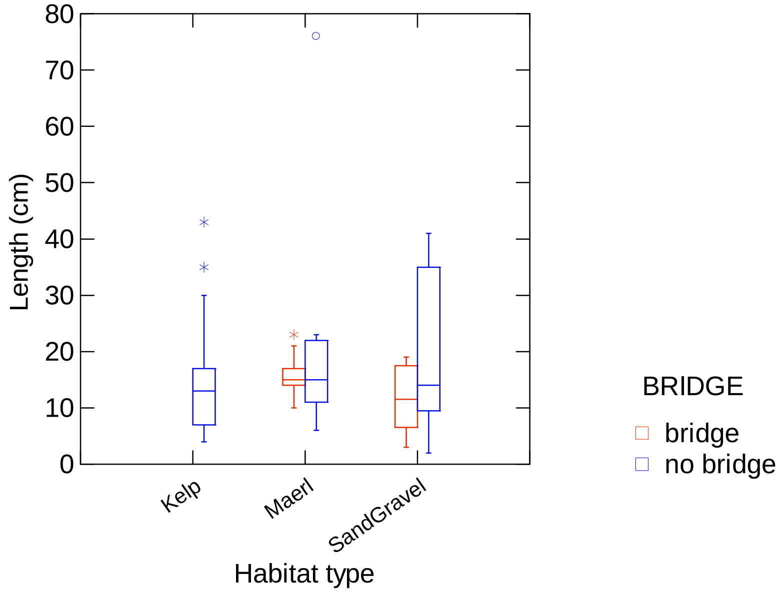

Figure 7. The length of juvenile gadoids caught at different substrate types in Hestfjörður and Skötufjörður (no bridge) vs Mjóifjörður (bridge), Oct and Nov. 2009.

Table 5. Results from ANOVA showing the effect of bridge and habitat type on by-catch size in Hestfjörður, Skötufjörður, and Mjóifjörður, Oct and Nov. 2009.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Bridge	335.419	1	335.419	7.389	0.009
Habitat type	271.728	2	135.864	2.993	0.060
Error	2178.924	48	45.394		

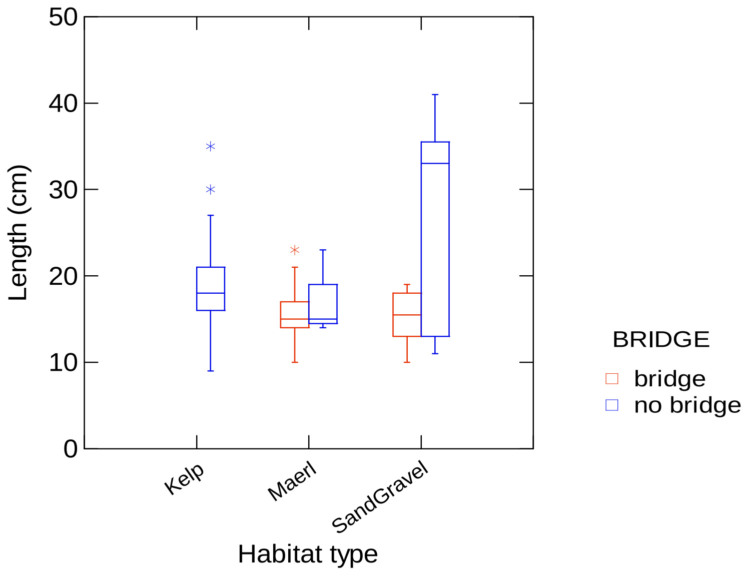

Figure 8. The length of by-catch species caught at different substrate types in Hestfjörður and Skötufjörður (no bridge) vs Mjóifjörður (bridge), Oct and Nov. 2009.

5. Discussion

The current study has three implications for the management of juvenile fish in Icelandic coastal waters. 1) Methods facilitating the sampling and monitoring of juveniles were developed and tested. 2) Catch of juveniles in the impacted fjord show that the bridge does not block movement of juveniles into the fjord. 3) Comparison of different benthic habitats suggests the importance of kelp for juvenile gadoids.

5.1. Validity and development of methods

In general the gill net sampling worked well in all the three habitat types tested and at depths ranging from 3 to 20 meters. The great majority of fish obtained were by the net with a 9.5 mm mesh size (table 1); the 6.5 mm mesh net sampled only the smallest individuals. The CPUE from the gillnetting compare reasonable to densities indicated by previous studies (Tupper & Boutilier, 1995; Shaw, et al., 2008). However, unofficial data from the Marine Research Institute suggest that juvenile cod numbers were unusually low in Ísafjarðardjúp in the fall of 2009 (Hjalti Karlsson, personal communication) and this is likely to be reflected in the numbers reported in the current study.   For the baited camera system observations the total number of gadoid juveniles seen equaled 4, with an average of less than one fish observed per sampling effort, suggesting a low density of fish throughout the studied fjords. It is likely that the deployment time allowed for this study, which equaled 30 minutes, is not optimal for observing the total number of fish attracted by the bait. Stoner, et al., (2008) while examining the appropriate duration for the camera observations determined that for juvenile Pacific gadoids the optimal time was 15 minutes, no such standards have been examined for Atlantic gadoids in Icelandic waters. For any subsequent studies the optimal time for observing fish abundance should be determined and used for the baited camera system. The extremely low number of fish observed, one fish or less over a period of 30 min vs. more than 10 fish observed over a similar period by Stoner, et al., (2008), could be improved by allowing a greater time of deployment for the Westfjords' studies.

Overall, there were fewer than expected juvenile gadoid fish present in the studied area; the relative low density of juvenile cod is also confirmed by underwater photography, possibly indicating a year experiencing very low abundance of juvenile gadoids in the region. Corresponding to claims that pronounced inter-annual fluctuations are present in juvenile cod abundance throughout Iceland (Jonasson, et al., 2009). However, there is large discrepancy between the gill net results and the camera results for the kelp dominated habitat. For the stations in the kelp habitat the underwater camera detected only one juvenile gadoid fish, while the gill net data suggested the greatest concentration of juvenile gadoids in the kelp habitat. The observed differences can be explained through the fact that kelp, as compared to the other two habitats, greatly affects the sight distance of the camera by obscuring most of the vision of the camera. It can be concluded that while underwater video and photography can be used to determine fish density in certain habitats such as sand, gravel, rock and maerl, it is not efficient in habitats dominated by various macro algae cover, such as kelp, that limit the visibility. The lack of success with the baited camera system in the heavily vegetated areas is contrary to other studies of similar scope that have shown relative success in different types of habitats including kelp. Stoner, et al., (2008) have found uniform results when using a baited camera system on three types of habitat (bare sediment, eelgrass and kelp). The apparent issues within the kelp habitat sampling could be improved in future studies by modifying the metal triangle used in this study to have a flat bottom that would serve as a platform and create an area free of vegetation where it is placed, creating more visibility surrounding the bait bag.

5.2.Impact of bridge construction

Overall, very few juvenile cod were present within the sampled fjords. Hence, all statistical analysis presented in this case study is based on the limited available data and should be interpreted accordingly. However, when interpreted with caution the limited data does not affect the basic validity of this study or any of the conclusions drawn. The present study represents only a snap-shot in time following the completion of the road and bridge and attempts to aid the management of the coast by also proposing additional studies that go beyond any environmental impact assessment (EIA) which frequently suffers from lack of more integrated and connected research (Cashmore, 2004). There is a need to monitor juvenile fish over the course of several years or even decades in the shallow habitats of the Westfjords and the study undertaken here can be used as a first year set of data on the abundance and diversity of different fish species in the respective fjords. Replicate sampling in subsequent years can contribute to long term data needed for the temporal monitoring of juvenile gadoid fish.

There was not a significant difference in gadoid juvenile numbers or size among the fjords. These results should be strengthened by additional sampling allowing for a much greater statistical power. However, there where slight differences among impacted and un-impacted fjords when including by-catch data. The Shannon diversity index for the gill net by-catch illustrates a higher diversity index for the un-impacted fjords and there were significant differences between the impacted fjord and the un-impacted ones for the by-catch finfish size. The un-impacted fjords supported larger sized fish indicating a higher abundance of adult fish. The by-catch data for the finfish did not present any significant differences among the different habitat types. Layman, et al (2007) showed that impacted habitats revealed a reduction in species diversity of over 90% in some extreme cases (Layman, et al., 2007), while Beach (2002) shows that altered habitats throughout North America lead to less species diversity (Beach, 2002). While the differences in the diversity index experienced in the Westfjords study are extremely subtle, this study does suggest possible species diversity impacts due to the bridge construction, a subject of further research. In particular, these results might suggest that although larvae and small pelagic juveniles are easily carried with currents into Mjóifjörður the movements of adults and larger fish are more restricted by the bridge, this warrants further study.

It is important to keep in mind that the little variability that is present among the impacted and the un-impacted fjords throughout the data presented could be sufficiently explained by chance or other variables present in the respective fjords such as predator and prey abundance or other temporal differences such as temperature, salinity or turbidity. Turbid waters can reduce the foraging area available (Vogel & Beauchamp, 1999) while less turbid waters can lead to increased predation due to better visibility (de Robertis, et al., 2003) implying a possible preference for specific intermediate turbidity levels by marine fishes (Meager & Utne-Palm, 2008). No standardized tests were performed on the water's turbidity, salinity and temperature; although visibility was determined to be the same in all sampling sites through researchers' visual observations.

Even if the current study found no difference in gadoid numbers among fjords this does not exclude potential future effect of the bridge on juvenile gadoids. As the bridge is a very recent structure any effect observed now was expected to be primarily through the bridge physically limiting the number of juvenile fish entering the fjord. Future effects through ecosystem changes have not been ruled out by the current study. Increased human development within the watershed will contribute significant pollutants, impacts proven to be magnified in altered bays or other semi-enclosed water bodies elsewhere (OzCoasts, 2009). Additionally, hydrologic alterations can have significant impacts on the ecosystem but exhibit a time lag and are less obvious in the short run. Repercussions of the bridge construction in

Mjóifjörður not observed yet because of a potential time lag as well as the possible implications if the region experiences increased human development could not be accounted for in this case study but can and should be expanded upon for future studies on the subject.

The use of the results from this study should be limited to fjords and water bodies with similar hydrologic characteristics. Due to the fact that the main changes of the bridge and road construction are in relation to the water currents (figures 2 and 3), which in turn are related to fjord topography, other fjord ecosystems experiencing similar construction projects but having dissimilar topography might respond differently to the changes due to the differences in physical properties within the fjord. As an example, in the southern part of the Westfjords: Thorskafjörður, Djúpifjörður, Gufufjörður and a fjord carrying the same name: Mjóifjörður, are being considered to undergo similar bridge construction projects (Thórisson, 2009). Due to the different hydrologic make-up of the southern fjords, most notably the shallow topography found throughout Breiðafjörður essentially rendering the fjords large mudflats, the changes posed by the bridge construction might not equal the changes experienced in the fjord referred to in this study. Warranting additional individual studies in those fjords using similar methods as performed in this case study.

6. General management implications

The gill net gadoid fish data demonstrates that a preference was found in the kelp dominated habitats with more fish being caught in the kelp habitat than the others combined. This preference for the kelp habitat can be explained to the fact that heavily vegetated habitats are generally preferred by juvenile gadoid fish because they offer more protection from predators (Borg, et al., 1997). This preference for the kelp habitat could not be explored in the impacted fjord because no kelp habitat was found in Mjóifjörður. Moreover, there was a significant difference in the size of the gadoid fish in relation to the different habitats.

Juvenile gadoid fish were slightly smaller in the sand and gravel habitat versus the other two habitats. Therefore, the results from the current study highlight the importance of including information on variable habitat and substrate types in coastal waters in management decisions.

Currently there is a realization that in order to reduce the decline in commercial fish populations a direct reduction in the fishing pressure through fishing capacity reduction is often being proposed (Pauly, et al., 2002; Schiermeier, 2002). Nonetheless, indirect effects on fisheries such as habitat destruction, alteration or degradation might also affect successful fish recruitment such as cod (Lindholm, et al., 1999) and explain decreases in stocks (Stal, et al., 2008). Other studies have demonstrated that commercial fish populations are limited by the availability of juvenile habitats (Juanes, 2007). Consequently, better protection through proper management of the juvenile fish habitat while not jeopardizing pressing infrastructure development projects can be crucial to the overall management of an important natural resource. Identifying important habitats and alterations to coastal waters and their effects on demersal juvenile gadoid fish will assist in the progress of knowledge toward better coastal resource management.

The validity of this study in reference to general coastal resource management should not be understated. Given the social and economic importance of Atlantic cod to Iceland, there is a clear need to better understand the habitat of the juveniles and how they are affected by human development. Infrastructure developments, such as bridges, throughout the country are vital for the economic prosperity and existence of the country’s remote cities and towns. It is recognized that coastal managers, may they carry that title or be politicians, scientists, or even fishermen must see the need for infrastructure development while not endangering the natural resources that the community depends on the most. In a rural region already troubled by population decline, decision makers are considering road infrastructure development as vital in keeping a close connection with the capital region and attempting to stem the social decline plaguing almost every region of the country outside the capital area. At the same time protecting the regional natural resources, commercial fish stocks in most of Iceland, is fundamental in maintaining the local economies which depend heavily on them. Consequently, any coastal management decisions made regarding the protection of coastal communities must understand the extremely sensitive balance between development and natural resource management; both of which can be sustained and developed if their effect on one another is well understood. The underlining theme that emerges from the constant battle of proper coastal management is always a better understanding of cause and effects of the various decisions made. Appropriately, in the case of the Westfjords, the vital infrastructure development must be understood in the context of its possible effects on the indispensable natural resource which is the Atlantic cod and other commercial gadoid fish.

Therefore, it is hoped that the study undertaken here, although it suggests that no impact on *G. morhua* or other gadoid fish abundance is being observed from the Mjóifjörður bridge construction, does present the need to better understand the possible implications that such coastal engineering projects might have on the local ecosystem and aid in the decision-making process that coastal managers are constantly faced with.

7. Summary

The study presented here examined the efficiency and potential of different methods which can be used in the monitoring and sampling of juvenile demersal fish in the Westfjords area of Iceland. Traditional methods of sampling marine fish are often not adequate for the juvenile stages because of the destructive nature of the techniques in shallow areas. Sampling methods that are not destructive to the coastal habitat but accurately and unbiasedly depict field observations are uncommon and not adequately researched. The trials this study presented with a previously un-tested baited camera system in conjuncture with a traditional method using gill nets, gives the first set of data regarding such methods in the region. This study also investigated whether or not a bridge construction in Mjóifjörður has had any immediate effects on the demersal juvenile gadoid fish present in the fjord. The results show no significant results in regards to the abundance and distribution of juvenile fish in the impacted versus the un-impacted fjords but do show the importance of kelp habitats for juvenile demersal fish in the region. Taken together, the issues investigated in this paper are aimed to aid in the proper management of the region's vital coastal resources. By suggesting all potential considerations needed to be taken in the management of Ísafjarðardjúp's coastal zone it is hoped that more integrated solutions will emerge.

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