Shifts in Spatio-Temporal Fishing Behaviour in the Canadian Pacific Halibut Hook and Line Fishery as a Result of a Choke Species

Tiare Boyes

Advisor: Robyn Forrest Ph.D.

University of Akureyri
Faculty of Business and Science
University Centre of the Westfjords
Master of Resource Management: Coastal and Marine Management
Ísafjörður, February 2018
Supervisory Committee

Advisor:
Robyn Forrest, Ph.D.

Reader:
Megan Peterson, Ph.D.

Program Director:
Catherine Chambers, Ph.D.

Tiare Boyes
*Shifts in Spatio-Temporal Fishing Behaviour in the Canadian Pacific Halibut Hook and Line Fishery as a Result of a Choke Species*

45 ECTS thesis submitted in partial fulfilment of a Master of Resource Management degree in Coastal and Marine Management at the University Centre of the Westfjords, Suðurgata 12, 400 Ísafjörður, Iceland

Degree accredited by the University of Akureyri, Faculty of Business and Science, Borgir, 600 Akureyri, Iceland

Copyright © 2018 Tiare Boyes
All rights reserved

Printing: Háskólaprent, Reykjavík,
Declaration

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

[Signature]

Jiare Bajeo.
Abstract

Marine capture fisheries can be characterised by a combination of biological factors governing fish productivity and social factors governing fishers’ behaviours. Most fisheries science research has focused on the biological side of fisheries but few studies have attempted to combine quantitative analysis of fishing data with qualitative study of active fishing participants. Choke species, or species with a low quota allocation in contrast to their encounter rates, may present a particular challenge to management of multispecies fisheries. Choke species may restrict fishers’ ability to harvest other species, especially in the presence of at-sea monitoring, which prevents discarding of regulated species. This thesis combines a quantitative spatio-temporal analysis of the potential impact of a choke species on fishers’ behaviour in the British Columbian Pacific Halibut (*Hippoglossus stenolepis*) fishery with a qualitative analysis of fishers’ reactions to reductions in the quota of bycatch species, Yelloweye Rockfish (*Sebastes ruberrimus*). Novel criteria were developed and employed to determine if Yelloweye Rockfish acts as a choke species within the Pacific Halibut fishery. Inter-annual and seasonal fishing effort dynamics were studied in years “prior” to (2007-2015) and “post” (2016-2017) a large reduction in the Total Allowable Catch (TAC) for Yelloweye Rockfish. A cluster analysis based on a previous study was developed to identify individual skippers’ “fishing opportunities” (i.e., individual fishing grounds on a fine spatial scale) and track usage of fishing opportunities in “prior” and “post” years. Interviews with five active skippers were conducted to corroborate interpretation of the data analysis. Results indicate that fishers have been successful in reducing their Yelloweye Rockfish catches since the TAC reductions, through a series of avoidance fishing tactics, including shifting into deeper waters, seasonal shifts and the decreased utilization of areas with high proportion of Yelloweye Rockfish in the catch. Studies such as this can help understanding of the potential spatio-temporal impacts of further TAC reductions for Yelloweye Rockfish. More broadly, this thesis improves understanding of strategies that fishers can employ to comply with catch regulations in monitored multispecies fisheries, which may help improve design of management strategies in the future.
I dedicate this thesis to my parents, Judy McLaren and David Boyes, who have always, without fail, supported me, no matter what endeavours I set my mind to.

I also dedicate this thesis to my partner Tim Courtier, who refuses to accept any limitations to what I can accomplish in life and who always has a solution to any problem that might arise.

And finally, I dedicate this thesis to the fish.
**Foreword**

I have been employed as a deckhand for 15 years within the B.C. Halibut commercial fishery working on my Father’s fishing vessel. I grew up in the fishing community on Vancouver Island and have always had a keen interest in fish biology and the intricate dynamics of marine ecosystems. After I completed my undergraduate degree in Environmental Studies at UVic, I decided I wanted to pursue a master’s degree in fisheries management combining my academic interests with my at-sea experiences. I hope, through my work, to help bridge the gap between fishers/food producers, fishery scientists/managers and consumers. I was hired by the Canadian Department of Fisheries and Oceans for the duration of my thesis to work on this project because of my experiential at-sea knowledge of the fishery. The people I worked with at the Pacific Biological Station were exceptionally hardworking, helpful and generous with their time and knowledge.
# Table of Contents

Abstract........................................................................................................................................... v

Table of Contents ................................................................................................................................. ix

List of Figures .......................................................................................................................................... xiii

List of Tables ........................................................................................................................................ xviii

Acronyms and Definitions .................................................................................................................. xix

Acknowledgements ............................................................................................................................ xx

1 Introduction ........................................................................................................................................ 1

1.1 British Columbia Commercial Hook and Line Pacific Halibut Fishery ........................................ 1

1.1.1 Spatio-temporal distribution of the hook and line Halibut fleet ............................................. 2

1.2 Hypothesis: ..................................................................................................................................... 4

1.3 Research Question: .......................................................................................................................... 4

1.3.1 Sub Research Questions: .......................................................................................................... 4

1.4 Research Aims and Overview of Methods ..................................................................................... 5

2 Theoretical Overview ....................................................................................................................... 7

2.1 Fish to Feed the World .................................................................................................................. 7

2.2 Confronting Common Property and the Race to Fish ................................................................. 9

2.3 Input/ Output Controls ................................................................................................................ 10

2.3.1 Input controls .......................................................................................................................... 10

2.3.2 Output controls ....................................................................................................................... 12

2.4 Incentive Based Management Strategies ..................................................................................... 12

2.5 Individual Transferable Quota Systems ....................................................................................... 14

2.6 Managing Multispecies Fisheries under ITQs and Choke Species ........................................... 16

2.7 Key Species within the British Columbia Hook and Line Pacific Halibut Fishery 19

2.7.1 Pacific Halibut (Hippoglossus stenolepis) ............................................................................. 20

2.7.2 Yelloweye Rockfish (*Sebastes ruberrimus*) ....................................................................... 20
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8</td>
<td>Groundfish Hook and Line Fishery History</td>
<td>21</td>
</tr>
<tr>
<td>2.9</td>
<td>Stakeholder Engagement and the Value of Combining Quantitative and Qualitative Research Methods</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>Methods</td>
<td>29</td>
</tr>
<tr>
<td>3.1</td>
<td>Study Location</td>
<td>29</td>
</tr>
<tr>
<td>3.2</td>
<td>Fishery Data</td>
<td>32</td>
</tr>
<tr>
<td>3.3</td>
<td>Fishery Independent Scientific Survey Data</td>
<td>33</td>
</tr>
<tr>
<td>3.3.1</td>
<td>IPHC Annual Setline Survey</td>
<td>33</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Depth stratified, random design longline research survey</td>
<td>35</td>
</tr>
<tr>
<td>3.4</td>
<td>Data Exploration</td>
<td>37</td>
</tr>
<tr>
<td>3.4.1</td>
<td>Licence scope</td>
<td>37</td>
</tr>
<tr>
<td>3.4.2</td>
<td>Spatial scope and fishing effort distribution</td>
<td>37</td>
</tr>
<tr>
<td>3.4.3</td>
<td>Inter-annual scope and intra-annual seasonal patterns</td>
<td>39</td>
</tr>
<tr>
<td>3.5</td>
<td>Depth Analyses</td>
<td>40</td>
</tr>
<tr>
<td>3.6</td>
<td>Location of Fishing Grounds</td>
<td>40</td>
</tr>
<tr>
<td>3.6.1</td>
<td>Fishing locations prior and post- Yelloweye quota reduction</td>
<td>40</td>
</tr>
<tr>
<td>3.7</td>
<td>TAC and Catch ratios</td>
<td>41</td>
</tr>
<tr>
<td>3.7.1</td>
<td>TAC Ratios</td>
<td>42</td>
</tr>
<tr>
<td>3.7.2</td>
<td>Catch Ratios</td>
<td>42</td>
</tr>
<tr>
<td>3.8</td>
<td>Cluster Analysis to Identify Fishing Opportunities</td>
<td>43</td>
</tr>
<tr>
<td>3.8.1</td>
<td>Clustering methods</td>
<td>44</td>
</tr>
<tr>
<td>3.9</td>
<td>Interviews with Individual Skippers</td>
<td>48</td>
</tr>
<tr>
<td>3.9.1</td>
<td>Influences on fishing behaviours</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>Results</td>
<td>51</td>
</tr>
<tr>
<td>4.1</td>
<td>Data Exploration</td>
<td>51</td>
</tr>
<tr>
<td>4.1.1</td>
<td>Overview of spatial and temporal changes in the fleet</td>
<td>51</td>
</tr>
<tr>
<td>4.1.2</td>
<td>Yelloweye TAC</td>
<td>53</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>4.1.3</td>
<td>Intra-annual seasonal patterns</td>
<td>57</td>
</tr>
<tr>
<td>4.2</td>
<td>Depth Analysis</td>
<td>60</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Fishery independent survey depth data</td>
<td>60</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Commercial depth data</td>
<td>61</td>
</tr>
<tr>
<td>4.3</td>
<td>Location of Fishing Grounds</td>
<td>67</td>
</tr>
<tr>
<td>4.3.1</td>
<td>Fishing locations prior and post- Yelloweye quota reduction</td>
<td>67</td>
</tr>
<tr>
<td>4.4</td>
<td>TAC and Catch Ratios</td>
<td>68</td>
</tr>
<tr>
<td>4.5</td>
<td>Cluster Analysis</td>
<td>69</td>
</tr>
<tr>
<td>4.5.1</td>
<td>Utilization Ratios</td>
<td>77</td>
</tr>
<tr>
<td>4.6</td>
<td>Interview Analysis</td>
<td>91</td>
</tr>
<tr>
<td>4.6.1</td>
<td>Influences on Fishing Behaviours</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Discussion and Conclusion</td>
<td>109</td>
</tr>
<tr>
<td>5.1</td>
<td>Discussion</td>
<td>109</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Is Yelloweye a choke species within the integrated Pacific Canadian hook and line commercial Halibut fleet?</td>
<td>109</td>
</tr>
<tr>
<td>5.1.2</td>
<td>What are the inter-annual and intra-annual patterns within the Halibut fleet?</td>
<td>111</td>
</tr>
<tr>
<td>5.1.3</td>
<td>What is the depth range of Halibut and Yelloweye in fisheries independent surveys and commercial fishing sets?</td>
<td>112</td>
</tr>
<tr>
<td>5.1.4</td>
<td>Is there evidence commercial Halibut fishers have an incentive to avoid Yelloweye?</td>
<td>113</td>
</tr>
<tr>
<td>5.1.5</td>
<td>What are the differences in spatial and seasonal fishing patterns before and after the 2016 reduction of the Yelloweye TAC?</td>
<td>114</td>
</tr>
<tr>
<td>5.1.6</td>
<td>Seasonal shifts and choke species</td>
<td>117</td>
</tr>
<tr>
<td>5.1.7</td>
<td>Avoidance behaviours</td>
<td>119</td>
</tr>
<tr>
<td>5.1.8</td>
<td>Unexpected results</td>
<td>121</td>
</tr>
<tr>
<td>5.1.9</td>
<td>Study limitations</td>
<td>122</td>
</tr>
<tr>
<td>5.1.10</td>
<td>Implications of major findings</td>
<td>123</td>
</tr>
</tbody>
</table>
5.2 Conclusion............................................................................................................. 127

References .................................................................................................................. 128

Appendix A ................................................................................................................. 151

Appendix B ................................................................................................................. 153

Appendix C ................................................................................................................. 158

Appendix D ................................................................................................................. 160
List of Figures

Figure 1: Pacific Halibut (Hippoglossus stenolepis) (DFO, 2000a) ................................................. 20

Figure 2: Yelloweye Rockfish (Sebastes ruberrimus) (DFO, 2000b) ............................................. 21

Figure 3: Department of Fisheries and Oceans Canada’s Pacific Groundfish Management Area of the coastal waters of British Columbia. Red circle indicates area of study for this analysis, Areas 5A, 5B, 5C, 5D and 5E (Map adapted from (DFO, 2017)). ............................................................................................................... 30

Figure 4: Line density map indicating changes over time of the setline catch density (kg per square km) of Pacific Halibut caught by the B.C. hook and line commercial fishing fleet for years 2007, 2015 and 2017. Setline frequency for all sets in Area 5 and Area 3 for each year. Setline Catch Density values (1-10) are ten equal groups over which the setline catch density is divided and should be interpreted as relative values. Data with fewer than three vessels per 4 km2 cells are not shown due to Privacy Act restrictions (Privacy Act, 1985). Source: DFO unpublished data. ...... 31

Figure 5: Line density map indicating changes over time of the setline catch density (kg per square km) of Yelloweye Rockfish caught by the B.C. hook and line commercial fishing fleet for years 2007, 2015 and 2017. Setline Catch Density values (1-10) are ten equal groups over which the setline catch density is divided and should be interpretive as relative values. Data with fewer than three vessels per 4 km2 cells are not shown due to Privacy Act restrictions(Privacy Act, 1985). Source: DFO unpublished data. ................................................................. 32

Figure 6: IPHC Scientific Setline Survey design in B.C.. Red dots indicate actual areas where setlines are sampled on a 10 nautical mile grid using standardized bait and gear from 2007-2017. ............................................................................................................. 34

Figure 7: OAHBLH scientific rockfish stock assessment survey 2006-2016. Data not available yet for 2017. .................................................................................................................................................. 36

Figure 8: Fishing Opportunities cluster example with multiple sets (along the x axis) illustrating the fishing opportunities obtained with a cut point of 0.23 km (red line). Distance between each set (km) is on the y-axis. Clusters above the cut point are considered unique fishing opportunities (adapted from (Branch et al., 2005). In this illustrative example there are 17 fishing opportunities, which can be calculated from the number of vertical lines intersected by the red line. ......................... 45

Figure 9: a) Annual number of sets for all Pacific Halibut hook and line L licence fishery sets from 2007-2017 coastwide (all management areas). b) Annual Number of Skippers within the L Licence Pacific Halibut Hook and Line Fishery from 2007-2017 coastwide (all management areas). c) Annual Number of Vessels within the L Licence Pacific Halibut Fishery 2007-2017 coastwide (all management areas). ..... 52

Figure 10: Total Allowable Catch of Halibut (tonnes) allocated to the B.C. Halibut hook and line commercial fishery (all management areas), between 2007 and 2017. .... 53
Figure 11: Annual coast-wide Yelloweye TAC across all sectors (blue) and allocated to the L License category (orange) from 2007-2017 ................................................................. 54

Figure 12: Proportion of landed Yelloweye by Area 5 sub-areas in spring and summer months from 2007-2017 ................................................................. 55

Figure 13: Area 5 A, B, C, D and E OAHBLH survey data indicating the number of Yelloweye per km2 over OAHBLH survey years. Note different scales. Source: DFO, unpublished data ................................................................. 56

Figure 14: (a) Proportion of B.C. Halibut hook and line sets and (b) Proportion of Landings (all species) throughout the seasons Fall & Winter (September-November) and Spring & Summer (March-August) from 2007-2017 ................................................................. 57

Figure 15: Polar histograms of annual number of sets by month throughout the B.C. Halibut hook and line fishing season from 2007-2017, and for all years (last figure) for all skippers. Dotted coloured lines indicate number of sets (see legend). Source: DFO, unpublished data ................................................................. 58

Figure 16: (a) Total landed Yelloweye in kg annually from 2007-2017 and (b) total landed Yelloweye in kg in spring and summer prior to (2007-2015) and post Yelloweye reductions (2016-2017) ................................................................. 59

Figure 17: (a) Proportion of landed Yelloweye annually by spring and summer and (b) Proportion of landed Yelloweye in spring and summer in prior (2007-2015) and post Yelloweye reductions (2016-2017) ................................................................. 60

Figure 18: Annual histograms of the depth distribution of IPHC scientific survey sets which encountered Halibut (in blue) and Yelloweye (in orange) a) 2007 b) 2015 and c) 2016. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps. d) Figurative Venn diagram of overlapping Halibut and Yelloweye depth distributions from the annual IPHC fishery independent survey ................................................................. 61

Figure 19: Annual histograms of the depth distribution of commercial fishery sets, which encountered Halibut (in blue) and Yelloweye (in orange) a) 2007 b) 2015 and c) 2017. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps. d) Figurative Venn diagram of overlapping Halibut and Yelloweye depth distribution encounters from commercial data ................................................................. 62

Figure 20: Annual histograms by season (spring and summer) of the depth distribution of commercial sets that encountered Halibut (in blue) and Yelloweye (orange): a) number of spring sets in 2007 by depth; b) number of summer sets in 2007 by depth; c) number of spring sets in 2015 by depth; d) number of summer sets in 2015 by depth; e) number of spring sets in 2017 by depth; and f) number of summer sets in 2017 by depth. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps ................................................................. 63

Figure 21: Weekly set depths of the B.C. Halibut hook and line fishery from 2007-2017. Blue boxes indicated interquartile range for each week, grey vertical lines indicated
monthly divisions and black horizontal lines indicate the median depth of sets (note that months are offset by six months compared to Figure 22). ........................................... 64

Figure 22: Mean maximum daily depths of 19 tagged Pacific Halibut displaying offshore-onshore seasonal migration from Kodiak Island Alaska to Cape Flattery Washington (reproduced from Loher, 2011 with permission from the author) (Note that months are offset by six months compared to Figure 21). ............................... 65

Figure 23: a) Depth (m) of all B.C. Halibut hook and line sets from 2007-2017 in the spring (left panel) and in the summer (right panel); b) depth (m) of all Halibut hook and line sets which did not encounter Yelloweye Rockfish from 2007-2017 in the spring (left panel) and in the summer (right panel); and c) depth (m) of all Halibut hook and line sets which did encounter Yelloweye Rockfish in the spring (left panel) and summer (right panel). Boxes denote interquartile range of set depth. Horizontal black lines indicate median depth while black dots indicate mean depth of sets................................................................. 66

Figure 24: Effective fishing grounds in the B.C. Halibut fishery in a) spring months (March-April) and b) summer months (May-August) defined as groups of effective longline fishing sets that aggregate in the same geographic area. Data are presented in summary format in accordance to the Privacy Act (1985) for the time period and area of interest. Data not in accordance with this Act have not been included in these figures (Privacy Act, 1985). ................................................................. 68

Figure 25: Unique fishing opportunities for a randomly selected skipper. All identifying land features have been deleted to protect the skipper’s privacy. ...................... 70

Figure 26: Number of sets made by the top 80 skippers (by kg) within Area 5 in spring/summer seasons of the B.C. Halibut fleet from 2007-2017. .......................... 71

Figure 27: Number of fishing opportunities for the top 80 skippers (by kg) within Area 5 in spring/summer seasons of the B.C. Halibut fleet from 2007-2017 .......................... 71

Figure 28: Example of a selected spring-specialized skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017, separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities separated into spring and summer. ......................................................... 74

Figure 29: Example of a selected summer-specialized skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017 separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities, separated into spring and summer. ................................................................. 75

Figure 30: Example of a selected multi-season skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017 separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities, separated into spring and summer. ............................ 76
Figure 31: Number of sets in fishing opportunities in spring (coral) and summer (teal) from 2007-2017 for skipper: a) who has shifted sets from spring and summer in prior years (2007-2015) to exclusively spring after 2015 (post years); and skipper b) who has shifted from spring and summer sets in prior years to exclusively summer sets in post years. ........................................................................................................... 77

Figure 32: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2007-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one. ........................................................................................................... 79

Figure 33: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2009-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one. ........................................................................................................... 80

Figure 34: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2012-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one. ........................................................................................................... 82

Figure 35: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2014-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one. ........................................................................................................... 83

Figure 36: Scatterplot plots showing mean proportion of Halibut, Yelloweye and ‘other species’ (contains all other encountered species) in landed catch by utilization ratio and depth for one skipper (x-axis shows depth and y-axis shows utilization ratio): a) example of skipper who shifted into deeper waters; b) example of a potentially species-selective skipper (i.e., who increased fishing in fishing opportunities that had high proportions of ‘other’ species along with Halibut and Yelloweye (grey shading)); and c) example of shallow water skipper who maintained depth profile but abandoned fishing opportunities with Yelloweye (yellow shading). Category 1(abandoned) corresponds to -1 on the y-axis, Category 2 (negative) is below the dashed line and Category 3 (positive) is above the dashed line. ......................................................................................... 86

Figure 37: Base Case 2007-2017: Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: b) Mean proportion of Halibut (mean among sets within fishing opportunities) landed by the top 80 skippers (by landed kg) in spring and summer over utilization ratio categories: Category 1: abandoned,
Figure 38: Sensitivity analysis prior years defined as 2009-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

Figure 39: Sensitivity analysis prior years defined as 2012-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

Figure 40: Sensitivity analysis prior years defined as 2014-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

Figure 41: Chart of common B.C. Halibut fishing grounds with some of the associated common names, Halibut grounds circled in red. Data gathered from interviews with skippers in the hook and line fishery. Note: this chart of common fishing ground names is not exhaustive or exact and common names might be known differently by individual fishermen.

Figure 42: The Four Quadrant Integral Theory model (Wilber, 1998) applied to some of the many fishing effort decision drivers which influence spatio-temporal fishing behaviour. These factors were compiled from interviews with five active skippers.
List of Tables

Table 1: Species managed under the Halibut L Licence........................................ 151

Table 2: Fisheries Operations System (FOS) for the Groundfish Handbook with
descriptions of data categories................................................................. 160
Acronyms and Definitions

B.C. – British Columbia
CGIP- Commercial Groundfish Integration Program
COSEWIC- The Committee on the Status of Endangered Wildlife in Canada
CPUE- Catch per Unit Effort (weight or count over standardized number of hooks or length of set)
DFO- Department of Fisheries and Oceans Canada
EBFM- Ecosystems Based Fisheries Management
EEZ- 200 nautical mile Exclusive Economic Zone
FAO- Food and Agriculture Organization
FOS- Fisheries Operations System
GFBIO- Groundfish Biology
IFMP- Integrated Fisheries Management Plan
IPHC- International Pacific Halibut Commission
ITQ- Individual Transferrable Quota
IVQ- Individual Vessel Quota
OAHBLH- Outside Areas Hard Bottom Longline Hook Survey
PECH- European Parliament Committee on Fisheries
SDG- Sustainable Development Goals
SOFI- State of Food Security and Nutrition in the World
TAC- Total Allowable Catch
UN- United Nations
Acknowledgements

I would like to express my deepest gratitude to my advisor Robyn Forrest. I could not have written this thesis without her incredible depth of knowledge, endless patience and enthusiasm for the subject. I would also like to thank Katherine Bannar-Martin and Lisa Lacko who were unendingly encouraging and worked tirelessly to help with my R and ArcMap difficulties.

Many thanks to all those at the Pacific Biological Station who made me feel very welcome and answered my many questions as well as the staff at the International Pacific Halibut Commission who shared their expertise.

My eternal gratitude, to the crew of the Borealis I and the Fearless II who over the years have taught me the value of hard work, camaraderie and relentless cheer in the face of adversary, you have shaped (for the better) who I am today as a human being.

Finally, I want to thank all my interview subjects who were incredibly generous with their time and intricate knowledge of the B.C. commercial Halibut fishery.

This research was funded by the Department of Fisheries and Oceans Canada, groundfish QUAMS division.
1 Introduction

1.1 British Columbia Commercial Hook and Line Pacific Halibut Fishery

The British Columbia (B.C.) hook and line Pacific Halibut (*Hippoglossus stenolepis*), (referred to as ‘Halibut’ from hereon) fishery on the Pacific coast of Canada is an example of a multispecies fishery managed under an Individual Transferable Quota (ITQ) and Total Allowable Catch (TAC) system that enforces discard bans through a 100% at-sea monitoring and 100% dockside monitoring program (DFO, 2017). The hook and line sector is one of seven fleets managed under the Integrated Fisheries Management Plan (IFMP) for groundfish, which encompasses 77 species of groundfish including rockfishes (*Sebastes* spp., 35 different species), flatfishes (Halibut, soles and flounders (*Pleuronectidae*, *Bothidae*), roundfishes (Lingcod *Ophiodon elongates*, Pacific Cod *Gadus microcephalus*, Pacific Hake *Merluccius productus* and Sablefish *Anoplopoma fimbria*), sharks, skates and numerous other species (DFO, 2017). The fishery and its history are described in detail in Section 2.8.

The Halibut fleet has been chosen for this study because it is one of the most valuable groundfish fisheries on the B.C. coast (DFO, 2017) and it has had 100% at-sea and dockside monitoring since 2006, providing a detailed database with records of the spatial-temporal data of each skipper and every species caught, whether retained or released. This fishery is also ideal for studying the impacts of management actions on a multispecies fishery due to high overlap of Halibut and inshore rockfish species on a portion of the fishing grounds. Yelloweye Rockfish (*Sebastes ruberrimus*) has been chosen as a focal species because it is potentially acting as a “choke” species in the Halibut fishery. Yelloweye Rockfish (referred to as ‘Yelloweye’ from hereon) is frequently encountered concurrently with Halibut and was designated as ‘Special Concern’ by Canada’s Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2014, and as Special Concern under Schedule 1 of Canada’s *Species at Risk Act* in 2011 (Department of
Fisheries and Oceans, 2015; *Species at Risk Act, SC 2011, c. 29*). Under Canada’s Precautionary Approach Framework (DFO, 2006a), the Yelloweye Total Allowable Catch (TAC) has been notably reduced in recent (DFO, 2015a; DFO, 2016; DFO, 2017). Given reductions in its TAC, and its spatial overlap with Halibut, on certain fishing grounds, Yelloweye has the potential to act as a choke species in the Halibut hook and line fishery, where a choke species is defined as a species with a low TAC relative to encounter rates that may limit the ability of fishers’ to catch co-occurring species. More detailed, novel criteria for identification of choke species and an exploration of relevant literature will be presented in Section 2.

1.1.1 Spatio-temporal distribution of the hook and line Halibut fleet

An important outcome of the introduction of the 100%-monitored B.C. Integrated Groundfish Fishery is a high-resolution database of the spatio-temporal distribution of the groundfish fleet over the last 10 years. This unique dataset is protected by strict privacy regulations and can only be accessed by employees of the Department of Fisheries and Oceans Canada (DFO) (Access to Information Act, 1985; Privacy Act, 1985). As a result of this, there have been very few detailed studies of changes in fishing patterns in the groundfish fleet since the introduction of 100% observer coverage across all sectors of the groundfish fleet in 2006. However, there have been no studies to date on changes in spatio-temporal distribution of fishing since integration of the B.C. groundfish fishery, and no studies of spatio-temporal fishing behaviour in the B.C. hook and line fleet. The spatio-temporal effects of the recent reductions in Yelloweye TAC on fishing behaviour of the Halibut fleet have never been examined, yet they have the potential to significantly inform understanding of the impacts of choke species and adaptability of skippers in multispecies fisheries. Fishers’ behaviour can be instructive about the effectiveness of fisheries regulations but this area of study requires more research (Poos, Bogaards, Quirijns, Gillis, & Rijnsdorp, 2010; Salas, Sumaila, & Pitcher, 2004). For this thesis I will adopt the definition of fishing behaviour developed by Béné (1996), where the “fishing strategy is seen as the internal decision-making process used by the fisherman with respect to his constraint(s) and his objective(s) and the fisherman’s behaviour as the observable reflection of this strategy” (Béné, 1996, p. 564). With discard bans coming into effect within the European Union (Arnason, 1994; Hatcher, 2014) and more broadly around the
world to address weak species conservation concerns (Condie, Grant, & Catchpole, 2014), this area of fisheries science, studying fishers’ behaviours, requires more research (Batsleer, Poos, Marchal, Vermard, & Rijnsdorp, 2013). A study produced by the European Parliament's Committee on Fisheries (PECH) (2015) on the impact of choke species and potential solutions, acknowledges fisher’s fine scale knowledge of fishing opportunities and their ability to adapt their fishing behaviours to avoid choke species but considers the spatio-temporal catch composition data available for the Baltic Sea “too crude to develop a practical solution” (Zimmermann et al., 2015, p. 13). The spatio-temporal database of the B.C. Halibut fishery provides a unique opportunity to study the effects of choke species on fishers’ behaviour.

This thesis will provide the first evaluation of changes in spatial fishing patterns in the B.C. Halibut fishery since the introduction of 100% at-sea monitoring and ITQs in 2006. More specifically, this study will focus on changes in spatial fishing behaviour of the fleet as the result of a choke species, Yelloweye, following large reductions in TAC for this species. These analyses, will form the first part of a larger study being done at DFO, and will use spatial logbook data from the Halibut hook and line fleet to quantify spatial-temporal shifts in fishing effort before and after the Yelloweye reductions. The hook and line fleet is the only fishery permitted to target Pacific Halibut in Canada, B.C. and will be further referred to as the Halibut fleet or the Halibut fishery. Furthermore, seasonal patterns in fishing strategies will be evaluated. This thesis will adapt and apply novel methods developed by Branch et al., (2005) and Branch and Hilborn (2008); and will investigate key drivers for spatial shifts in fishing effort through analysis of species composition of the catch and interviews with skippers.

Through my experience within the fishery, it has become apparent that there are distinct seasonal variations between fishing strategies employed in the spring and those employed in the summer. The seasonal variations within the fishery are also accompanied by noteworthy differences between incidental catches of Yelloweye in the spring and summer fishing seasons. Loher (2011) examined mean maximum daily depths of tagged Halibut to study spawning ecology and commercial fishery season openings but did not elaborate on the commercial fishing behaviour. Differences in seasonal fishing strategies among skippers is common knowledge in the commercial fishery (e.g., due to differences in incidental rockfish catches in spring and summer), but has never, to my knowledge, been
studied. This study will focus on the L licence, or the directed Halibut fishery, and will be restricted to years from 2007-2017.

1.2 Hypothesis:

Yelloweye Rockfish is a choke species within the multi-species integrated Pacific Canadian hook and line commercial Halibut fleet (L licence category) and is a key driver in spatio-temporal fishing behavioural shifts in skippers’ fishing behaviour.

1.3 Research Question:

Yelloweye as a possible choke species has the potential to shape fishers’ spatio-temporal behaviours. It is important then, to examine skippers’ behavioural trends, catch composition changes and seasonal patterns among other factors before and after Yelloweye Rockfish TAC was reduced. Anecdotal information from the fishery suggests that intra-annual seasonal changes may also affect fishers’ behaviour. The following research question and sub-research questions seek to encompass all aspects of the issue to establish intra and inter-annual trends prior to the reductions and post reductions:

What are the characteristics of intra-annual and inter-annual fishing effort patterns prior to and post the 2016 Yelloweye Rockfish TAC reduction within the integrated Pacific Canadian hook and line commercial Halibut fleet?

1.3.1 Sub Research Questions:

1. Is Yelloweye a choke species within the integrated Pacific Canadian hook and line commercial Halibut fleet?
2. What are the inter-annual and intra-annual patterns within the fleet?
3. What is the depth range of Yelloweye Rockfish and Pacific Halibut habitat in the fisheries independent International Pacific Halibut Commission (IPHC) scientific survey?
4. What is the depth range of Yelloweye Rockfish and Pacific Halibut encounters within the commercial fishery?
5. What is the overlap depth range of Halibut and Yelloweye encounters within the commercial fishery and according to fisheries independent scientific surveys?
6. Is there evidence commercial Halibut fishers have an incentive to avoid Yelloweye Rockfish?
7. What are the differences in spatial and seasonal fishing patterns before and after the 2016 reduction of the Yelloweye TAC?

1.4 Research Aims and Overview of Methods

The purpose of this thesis is to: (i) provide a quantitative spatio-temporal analysis of the impact of a choke species on fishers’ seasonal and annual spatial fishing choices in the B.C. Halibut hook and line fleet; (ii) to collect preliminary qualitative data; and (iii) to connect the qualitative and quantitative components of the analysis. This will provide valuable insight regarding the human behavioural dynamic aspect of fisheries, which is integral to the design of predictive modeling tools to calculate the potential effects and the economic/environmental trade-offs of further quota reductions within multispecies fisheries (Forrest, 2008; Hilborn, Stewart, Branch, & Jensen, 2012). These tools help fisheries managers implement effective regulations for harvesters and producers (Forrest, Savina, Fulton, & Pitcher, 2015).

This thesis begins by identifying, through novel criteria, Yelloweye as a choke species within the Halibut fishery, which has the potential to impact fishers’ spatio-temporal fishing behaviour. Halibut and Yelloweye depth distribution are examined through various quantitative summaries, using data from the B.C. commercial Halibut fleet as well as two fishery-independent stock assessment surveys, the IPHC survey and the Outside Area Hard Bottom Longline Hook (OAHBLH) survey. Inter-annual patterns are explored through examining trends over the years spanning 2007-2017. Intra-annual patterns are examined between fishing seasons, as spring and summer have previously not been recognized as having distinct seasonal strategies. Spatial fishing effort trends in the Halibut fleet are examined using a year range “prior” to Yelloweye TAC reduction (2007-2015) and years “post” Yelloweye TAC reduction (2016-2017). Annual patterns in Yelloweye TAC and catch are calculated using formulas adapted from Branch and Hilborn’s (2008)
study. A cluster analysis is then performed using methods that were developed by Branch, Hilborn and Bogazzi (2005) for the Pacific groundfish bottom trawl fleet. Setlines are assembled into clusters using hierarchical agglomerative clustering based on the Euclidean distance between each set, thus clustering individual sets into “fishing opportunities”, defined as fishing grounds unique to individual skippers (Branch, Hilborn, & Bogazzi, 2005). A “utilization ratio” statistic (Branch & Hilborn, 2008) is developed to determine relative usage of fishing opportunities in years prior to and post a large reduction in the Total Allowable Catch (TAC) for Yelloweye. Selected fishing opportunities with negative utilization ratios (i.e., fishing grounds that have been visited less often since the Yelloweye TAC reduction) are examined to determine catch compositions to investigate attributes including proportion of Yelloweye and Halibut in the catch and depth. Proportions of fishing opportunities characterized by increased, decreased or unchanged utilization since Yelloweye TAC reductions are examined by season to investigate possible seasonal fishing effort shifts motivated by avoidance of Yelloweye habitat. Finally, results are verified through interviews and/or written surveys with active fishers who describe details of their spatio-temporal fishing choices.
2 Theoretical Overview

2.1 Fish to Feed the World

For the first time in over a decade, global hunger is on the rise. On September 15th 2017, the UN released the State of Food Security and Nutrition in the World (SOFI) report which highlighted that 38 million more people went hungry worldwide in 2016 than in 2015 (FAO, 2017). While recent conflict and natural disasters are major contributing factors to global food insecurity, food production industries and their long-term sustainability and efficiency should also be examined. With continued projected population growth, addressing food insecurity, malnutrition and obesity are at the core of the UNs 17 Sustainable Development Goals (SDGs) (General Assembly resolution A/RES/70/1). Nutritious and well-managed protein sources are needed, as “even a small quantity of fish can have significant positive nutritional impact on plant based diets” (FAO, 2016, p. 4). In 2015 the UN developed the 17 Sustainable Development Goals (SDGs). The SDGs provide a common base to set national and international standards to work towards achieving targets using SMART criteria, defined by the UN as Specific, Measureable, Achievable, Resource-based with Time-bound Deliverables (General Assembly resolution, 2016). Goal 14: Life Below the Water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development, highlights that marine protein production must be effectively managed to ensure the continued health and functioning of marine ecosystems, biodiversity and marine protein production (General Assembly resolution A/RES/70/1).

Harvesting food from the sea has been an important part of food production since prehistoric times and continues to this day to be a significant source of healthy protein world-wide (Sahrhage & Lundbeck, 1992). An increase in urbanization, infrastructure development and supply chain efficiencies has led to an increase in seafood demand and consumption worldwide (FAO, 2016, p. 176). The United Nations Food and Agriculture Organization (FAO) projects that within the next decade an increase of almost 31 million tonnes of world fish consumption will occur while, over three billion people depend on marine and coastal biodiversity for their livelihoods (FAO, 2016). Almost 17% of animal protein consumed globally comes from the ocean with an estimated 35 million jobs.
directly linked to marine harvest industries (FAO, 2016; Leslie et al., 2012). The Earth’s oceans provide not only sustenance for humans, but vital ecosystem services such as climate regulation, carbon cycling, coastal protection, aesthetic and cultural values as well as a richly complex habitat for marine species (Bigg, Jickells, Liss, & Osborn, 2003; Costanza et al., 1997; Martínez et al., 2007; Reid et al., 2009).

To ensure the continuation of these valuable ecosystem services and preservation of marine biodiversity, it is important that wild capture fisheries are sustainably managed. However, definitions of sustainable fisheries management vary among jurisdictions and international organizations (De Alessi, 2017). Hilborn et. al (2015) asked ‘when is a fishery sustainable?’ and investigated definitions of sustainability from Environmental Non-Governmental Organizations (ENGOs), seafood ecolabels such as the Marine Stewardship Council (MSC), the FAO, scientists and economists. They concluded that the most comprehensive definition was proposed by the World Commission on Environment and Development (1987), commonly known as the Brundtland Commission, which states:

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland & World Commission on Environment and Development, 1991; Hilborn et al., 2015, p. 1439).

Most perspectives on sustainability today, include the acknowledgement of not only biological and ecological elements but also social and economic dependency of coastal people on marine resources (De Alessi, 2008; Hilborn et al., 2015; Marshall et al., 2017; Wilson, Tyedmers, & Pelot, 2007). In the past, fisheries management often focused on maximizing yields of target species without much regard for the greater ecosystems (Pikitch, 2004). However, most fisheries today are multispecies in nature and harvesting a single species at its Maximum Sustainable Yield (MSY) can mean that other species encountered within those fisheries may be overfished or underutilized (Hilborn, Punt, & Orensanz, 2004; Hilborn et al., 2012). Ecosystem Based Fisheries Management (EBFM) has become the new internationally accepted management objective, which suggests that species should be managed not only as individual stocks, as was the previous approach, but as part of the greater dynamic ecosystem through protecting sensitive habitats, monitoring environmental indicators and preventing overfishing in all its forms (Larkin, 1996; Pikitch,
2004). However, it is important to note that EBFM, while widely adopted in theory, still in most cases relies upon single species stock assessments, which statistically integrate multiple data sources to estimate productivity and population size (Pikitch, 2004).

2.2 Confronting Common Property and the Race to Fish

Oceans and the organisms within them, are considered by some to be one of the last common pool resources (Fujita & Bonzon, 2005; Pinkerton & Edwards, 2009). Living marine resources are now largely managed by national governments as a result of the declaration of 200 mile Exclusive Economic Zones (EEZ) in most coastal jurisdictions (Huppert, 2005; UN General Assembly, 1982). Debate occurs when determining how to distribute access rights to such national resources (Huppert, 2005). At its most basic, fisheries management seeks to prevent fisheries from inflicting more mortality on renewable fish stocks than can naturally be absorbed by the stock through reproduction and growth (Branch et al., 2006). Fish, when managed as a common pool resource, are owned by everyone and, therefore, owned by no one (Fujita, Foran, & Zevos, 1998). Arguably until a fish is caught, it has no economic value because there is no ownership (Casey, Dewees, Turris, & Wilen, 1995; Griffith, 2008). Fishers under a common pool system have little incentive to practice conservative fishing. To competing fishers, it is rational to harvest fish at the maximum rate to out-compete rivals (Branch et al., 2006, p. 1662; Bromley, 2009; De Alessi, 2008; Fujita et al., 1998; Griffith, 2008). This is sometimes termed the “race to fish” (Casey et al., 1995; Fujita et al., 1998; Griffith, 2008; Hsueh, 2017). As Hardin wrote in his famous “Tragedy of the Commons” paper, drawing from economist W.F. Lloyd’s pamphlet (1833), increasing personal production is rational behaviour from the perspective of an individual, whereas it is irrational from the perspective of the collective because, when each individual attempts to extract more than their neighbour from the common pool, the negative effects are felt by all (Hardin, 1968; Lloyd, 1833). In multispecies, common pool fisheries, this can mean discarding of unwanted bycatch (incidentally-encountered non-target species) or high-grading (when fishers retain only the most valuable fish, characterized by weight class or species type, and discard the less valuable fish) (Kelleher, 2005; Parslow, 2010). The notion of
“freedom of the seas”, which pervades many cultures, adds to the pressure marine resource users put upon the sea, where the actions of a few who see free access and harvesting unsustainable levels of fish as their right, negatively affects the collective (Fujita & Bonzon, 2005; Parslow, 2010). The “race to fish” is bleakly illustrated by seasonally limited or “derby style” fisheries where fishing effort is controlled by limiting openings. For example, the Halibut fishery in British Columbia went from 65 days open in 1980, to only six days during in 1990, in which fishers fiercely competed to harvest their fish, at the risk of their safety and product quality (Casey et al., 1995; Chu, 2009).

2.3 Input/ Output Controls

In order to curtail the excess removal of fish, the role of managers is to restrict fishing effort or access (Torres-Irineo, Dreyfus-León, Gaertner, Salas, & Marchal, 2017). This can be accomplished in a variety of ways. Broadly, these can be “input controls”, which include spatial restrictions, access limitations (i.e., area and time closures), gear restrictions and size limits, or “output controls” which set the total allowable catch for a given fish stock (Anderson, 1999; Branch et al., 2006; Fujita et al., 1998; Walters & Martell, 2004).

2.3.1 Input controls

According to Morison (2004) Input controls seek to constrain fishing effort. Spatial restrictions, or area-based management strategies, have a long history in fisheries management (Costello et al., 2016). Closing areas to fishing is a simple and effective way of reducing fishing pressure in certain areas, yet boundaries are often drawn with political motivation or limited understanding of species distributions and at times fail to meet ‘weak stock’ (or low productivity stock) conservation targets (Ono, Holland, & Hilborn, 2013). Closing a historically productive fishing area can negatively affect the greater ecosystem in some cases, as greater overall impacts may arise from high intensity of displaced effort in areas previously not impacted by fishing (Jennings, Lee, & Hiddink, 2012). While measures such as Marine Protected Areas (MPA) may have conservation benefits for sensitive habitats and sessile communities such as coral reefs, hydrothermal vents and sponge reefs, accounting for migratory behaviour of fish species is difficult to manage using static boundaries (Holland & Schnier, 2006).
Access limitations or limited entry fisheries are designed to limit the number of fishers who can harvest fish, usually through a licensing system. This represents an improvement compared to open access systems but it can be politically and socially difficult for managers to minimize entry sufficiently to keep catches within sustainable limits (Fujita et al., 1998). This system also does not eliminate the ‘race to fish’ problem as there is still competition among skippers to get their catch before their competitors (Grafton, 1996). In systems such as this, fishers may invest in better technology, bigger boats and more power to gain a competitive edge. In order to finance these investments, they must increase effort and in most cases overfishing is not avoided (Turris, 2000). This “ratchet-like effect” describes the series of boom and bust markets associated with rapid investment in fishing resources, which precipitates the collapse of stocks due to overfishing, and is followed by a slow disinvestment reaction (e.g., vessel “buy-back” schemes) subsidized by governments (Ludwig, Hilborn, & Walters, 1993). Pitcher (2000) later called this theory ‘Ludwig’s Ratchet’, and it has been used to describe the groundfish collapse off the coast of New England (Healey & Hennessey, 2017).

Input controls may also be implemented by restricting gear technology, fishing season length and vessel capability (by restricting vessel size and mechanical abilities) (Branch et al., 2006; Walters & Martell, 2004). Fishers generally respond by developing innovative methods to maximize their efficiency (Grafton, 1996; Mawani, 2009). Inevitably, most input controls become an example of Van Valen’s (1973) “Red Queen” hypothesis, where each party is running as fast as they can to keep in the same place. Lewis Carol wrote in his famous book, Through the Looking Glass, “It takes all the running you can do to stay in the same place” (Carroll, 1871). In the 1970’s Van Valen used this theory to describe the evolutionary arms race between two organisms where each organism must keep evolving to maintain their place in the food chain (Van Valen, 1973). In the case of fisheries management, regulators create input control regulations by restricting fishing technology or fishing season length, while fishers evolve their fishing strategies to maintain their yields. Then, as fishers become more efficient at harvesting, fisheries managers evolve more stringent regulations and so it continues with neither party gaining much ground (Carmichael & Hadžikadić, 2015).
2.3.2 Output controls

Whereas input controls seek to constrain fishing effort, output controls seek to constrain actual catch (Morison, 2004). Output controls are applied through TAC restrictions, access rights (how much an individual is actually allowed to catch), and quota management systems, all of which control how many fish are actually being caught (Branch et al., 2006). Output control systems have been adopted in many countries around the world and have been widely endorsed as having desirable outcomes when properly implemented (Costello, Gaines, & Lynham, 2008). Stock assessment models are often a necessary component of output control systems, which require estimates of sustainable harvest rates in order to effectively set catch limits (Walters & Martell, 2004). ‘Derby style fishing’ is typically a result of a TAC that is allocated to the fleet collectively, which puts all fishers in direct competition to out-fish their neighbours (Walters & Martell, 2004). Output controls require monitoring systems, enforcement programs and effective governance to ensure compliance; this often comes with high operational costs borne by fishers (Branch et al., 2006).

Controlling access or effort or even TAC does not always meet conservation goals as fishers’ adaptive strategies in response to regulations can lead to unforeseen consequences and possible failure to meet management objectives (Torres-Irineo et al., 2017). Designing management systems that are consistent with the existing social organization within fishing fleets and within the greater community and economic systems associated with fish products may be a better approach to meet sustainable management objectives. Incentive-based management strategies are an example of such an approach (Acheson, 1975).

2.4 Incentive Based Management Strategies

Implementing a regulatory framework that incentivizes fishers to act for the common good while at the same time maximizing individual returns, is the ultimate goal of fisheries management theory (Arnason, 1994). It has been suggested that, to avoid the race for fish, an approach different from the traditional top-down fisheries management system is required (Emery, Green, Gardner, & Tisdell, 2012). Incentive-based management, or the participatory approach, is described by Hilborn (2004) as a “carrot” approach to fisheries management as opposed to a top-down, “stick” approach. Incentive-based management
strategies can encourage stakeholder engagement in managing dynamic fisheries systems (Hilborn, 2004). This type of management can also promote generation of profits for fishing fleets, not by high volumes of landings, but by allowing fishers to produce high quality product and to market it strategically (Hilborn, Parrish, & Litle, 2005). Incentive-based fishery management theory endorses tenure or ownership of fishing rights to encourage individual investment (economically and professionally) in the conservation of fish stocks (Emery et al., 2012). While the incentive for conservation comes from guaranteed future individual access rights, effective enforcement is still required to hold individuals accountable for their actions, promoting a “collective strategy” whereby individuals may work together towards common goals rather than in competition against one another (Hilborn et al., 2005; Branch 2009). Salas & Gaertner, (2004) documented cooperative fishing strategies in both small-scale and industrial fisheries, e.g., fishers from the Yucatan, Mexico, who compete during portions of the year but share catches during other seasons. Information sharing amongst ‘code groups’ or ‘teams’ is also well documented in fisheries in Canada and the US (e.g. Lobster or Tuna) (Acheson, 1975; Torres-Irineo et al., 2017) and ‘quota pooling’ has been documented in several trawl fisheries whereby fishers share bycatch quotas to cover overages (Holland, 2010).

Bycatch, or the incidental encounter of a non-target species, is a problem in fisheries around the world, and increasingly fisheries are moving towards discard bans to decrease bycatch wastage (Dunn, Boustany, & Halpin, 2011; FAO, 2011b). Individual bycatch quotas can increase avoidance behaviour and decrease bycatch encounters by incentivising fishers (through penalties) to avoid bycatch species (Holland, 2010). In some cases, fishers are able to be highly selective of the fish they catch by altering their fishing gear, the season or depth at which they fish, choice of bait choice of tide cycle when their gear is deployed, or by varying soak times (Boyce, 1996; Branch et al., 2006; Branch & Hilborn, 2008). This measure of control that fishers can have over the proportions of different species caught, has largely been overlooked by researchers and managers (Branch & Hilborn, 2008). Creating incentives for fishers to use selective fishing behaviour, through monitoring and enforcement programs that result in avoidance of known habitat of bycatch species, may be an overlooked solution to the problem of bycatch in multispecies management and maintaining profitable fleets (Branch, 2006). Scientific research in fisheries has largely focused on stock assessments, fish ecology, biology and fishing effort
technology but few studies have investigated drivers of behaviour in individual fishers some notable exceptions including: (Branch et al., 2006, 2005; Branch & Hilborn, 2008; Fulton, Smith, Smith, & van Putten, 2011; Pelletier & Ferraris, 2000; Poos et al., 2010; Salas & Gaertner, 2004; Salas et al., 2004; Torres-Irineo et al., 2017; Walters & Martell, 2004). Gordon (1954) wrote in his paper on the economics of fisheries “the ecosystem of the fisheries biologist is typically one that excludes man” (Gordon, 1954). The ‘why’ of fishing drives the ‘where’ of fishing and many factors can influence fishers’ behaviour at sea which, in turn, can affect the abundance of fish stocks.

2.5 Individual Transferable Quota Systems

The Individual Transferable Quota system (ITQ), similar to the Individual Vessel Quota system (IVQ), was first introduced in the Icelandic Herring fishery in 1975 (Arnason, 2005). New Zealand adopted an ITQ system in October 1986 (Annala, 1996). The theory behind ITQ is rooted in incentive-based management. Within this system, governments set fleet-wide catch limits (i.e., TACs) for a fishery and are responsible for the enforcement of these catch limits (McCay, 1995). Individual fishers then control their individually allocated quota and may harvest, sell or temporarily transfer (lease) their quota as they see fit within the regulations (McCay, Creed, Finlayson, Apostle, & Mikalsen, 1995). Since their inception, there has been debate about the fairness and success of ITQ/IVQ systems (Bromley, 2009; Carothers & Chambers, 2012; Chambers, Helgadóttir, & Carothers, 2017; Pinkerton, 2013; Pinkerton & Edwards, 2009). However, ITQs or IVQs have been widely adopted and have been successful by many measures (Arnason, 2005; Costello et al., 2008; Edinger & Baek, 2015; Fujita & Bonzon, 2005; Hilborn et al., 2004; Worm et al., 2009). Arguments on both sides of the ITQ debate have merit.

Proponents argue that ITQ systems address common property problems or the ‘tragedy of the commons’ (Hardin, 1968; Parslow, 2010) and reverse the economic inefficiency of open access fisheries (Fujita & Bonzon, 2005; Grafton, 1996). Protection of marine ecosystems and fish stocks is often cited as a result of properly designed and implemented ITQ systems based on TAC limits in conjunction with other conservation measures (Arnason, 2005; Branch, 2009; Costello et al., 2008; Fujita et al., 1998; Grafton, 1996; Worm et al., 2009). Replacement of derby-style management with ITQs has been shown to
result in better quality of fish product as fishers are able to take more time to take care of their catch, resulting in increased marketability and profits (Branch & Hilborn, 2008; Jones & Bixby, 2003). It should be noted that the success of an ITQ based management system is widely accepted to be dependent on reliable monitoring and enforcement systems (Parslow, 2010).

Opponents argue that problems around initial access to quota at the inception of an ITQ system, and consolidation of fishing resources into the hands of a few, are unacceptable social outcomes (Bromley, 2009; Pinkerton & Edwards, 2009; but see rejoinder: (Turris, 2010) and rejoinder; (Pinkerton & Edwards, 2010). Consolidation of fleets often results from ITQ systems, as small quota owners may sell their shares to larger companies (Chambers et al., 2017; Olson, 2011). The consolidation of fleets can be seen both as a positive and negative result, as fewer fishers means less fishing gear and potentially less impact on the environment. However, fewer fishing boats can also mean fewer job opportunities in coastal communities, and can lead to the elimination of smaller fishing businesses (Olson, 2011). A common argument against ITQ systems is that they privatize common pool resources without proper compensation to the public (Bromley, 2009). Many also point out that privatization of resources has, historically, rarely resulted in the responsible use of resources (Clark, Munro, & Sumaila, 2010; Mansfield, 2004). Also, increased profitability following a change to ITQ management can increase the price of entry into the fishery, which may serve as a barrier to new and younger entrants (Branch & Hilborn, 2008; Carothers, 2015; Carothers & Chambers, 2012).

As some researchers have pointed out (Arnason, 2005; Shotton, 2000), care must be taken when discussing ITQ management systems, as private ownership rights are sometimes falsely attributed to ITQ catch shares (e.g., Bromley 2009; Pinkerton & Edwards, 2009). Right to access does not necessarily mean ownership, which usually remains with the government, or commons (McCay et al., 1995). According to some analysts ITQs provide not so much a ‘right’ as a ‘privilege’ to access (Grafton, 1996) and have been described as “property-like” (Scott, 2000) or “quasi-private property” (McCay et al., 1995). In Pacific Canada, recent court cases have demonstrated that the Minister of Fisheries may reallocate commercial fishing quota to the other fishing sectors without compensation to commercial fishers (Keleher, 2002; Malcolm v. Canada (Minister of Fisheries), 2014). The case was appealed to a higher court and dismissed with the finding that “The Minister’s decision fell
within a range of reasonable outcomes having regard for both the context in which the
decision was made and the discretionary and policy nature of the decision” (Malcolm v. Canada (Minister of Fisheries), 2014). In other words, in Canada, as in many jurisdictions, fisheries resources remain common property, even in the presence of ITQs, which are intended to serve as a mechanism for incentivising responsible use of common marine resources (Shotton, 2000).

2.6 Managing Multispecies Fisheries under ITQs and Choke Species

Multispecies fisheries, or mixed fisheries, occur when many different species are caught at the same time, using the same gear and are a representation of the ecological community of any particular fishing ground (Pelletier & Ferraris, 2000) (with the exception of trawl fishing which may capture species from a wide range of habitats due to the nature of the fishing technology and methods). These fisheries can be difficult to manage efficiently, as species of different productivities are caught together (Branch et al., 2006; Hilborn et al., 2004; Ono et al., 2013; Pitcher, 2001). Habitats of many marine species overlap which can make exploiting target species difficult while at the same time meeting conservation goals for species of concern (Hilborn et al., 2004; Worm et al., 2009). Dealing with the issue of wastage, or the discarding of low-value species in the interest of catching more high-value species, has been a problem in most fisheries around the world (Arnason, 1994). In Pacific Canada’s hook and line fishery, through the ITQ system, each species has catch and discard limits set by management area, and this species-area quota is transferrable among fishers (Mawani, 2009). This allows fishers to be flexible with their catch compositions, transferring quota to cover overages while not exceeding area or species TAC, and minimizing wastage. Jannot and Holland’s (2013) study suggested ITQs “can create incentives for fishers to avoid areas with high expected bycatch” rates (Jannot & Holland, 2013). In the past it has been assumed that multispecies fisheries inevitably maximize total yield for some species, while others are overexploited or underutilized making the FAO code of conduct for responsible fishing difficult to meet (Branch & Hilborn, 2008; FAO, 2011a; Hilborn et al., 2004; Ulrich et al., 2016). This paradigm has been challenged by Branch and Hilborn (2008) who showed that, through matching fishers’ actual catch to
TAC limits in Pacific Canada’s groundfish trawl fishery, fishers can be highly selective and can adapt to non-target species restrictions, while still harvesting target species at desired levels. These results are supported by other studies (Jannot & Holland, 2013; Quirijns, Poos, & Rijnsdorp, 2008). Fishers accomplish selectivity through a combination of avoidance fishing techniques which may include increasing or decreasing trawl speed (in trawl fisheries), selecting specific habitats or changing seasonal fishing efforts (Branch & Hilborn, 2008; Jannot & Holland, 2013; Mortensen, Ulrich, Hansen, & Hald, 2018).

High grading and discarding are two of the most serious challenges facing managers of multispecies fisheries. These are, at the individual skipper level, financially rational actions through which fishers seek to maximize their profits. However at the fleet or ecosystem-level, these actions can amount to another example of the tragedy of the commons (Hardin, 1968; Lloyd, 1833; McCay et al., 1995). Mitigation of the negative effects of high-grading, or wastage, is effectively addressed through limits on discarding or discarding bans enforced through mandatory at-sea monitoring programs and ITQ systems (Batsleer et al., 2013; Branch et al., 2006; Condie et al., 2014; Grafton et al., 2006; Mawani, 2009; Ono et al., 2013; Ulrich et al., 2016). In monitored multispecies ITQ fisheries, fishers are incentivised to target species with relatively high TAC allocation and avoid species with relatively low TAC allocation by adjusting factors such as where and when and how they set gear (Branch and Hilborn, 2008). By trading, leasing, buying and selling quota, fishers can create a portfolio of species that matches their strategies, yet little research has been done on these behaviours (Branch and Hilborn, 2008).

Non-target species for which there are conservation concerns (e.g., long-lived, low-productivity or high site-fidelity species with high post-capture mortality rates such as Pacific rockfishes (Sebastidae)) can be successfully managed through ITQ systems by decreasing the TAC on these species and enforcing a discard ban (Hannah & Rankin, 2011; Richards, 1986; Stanley, Karim, Koolman, & Mc Elderry, 2015). Individual quota for these species can become highly valued as fishers become restricted in their ability to harvest other target species without exceeding bycatch limits on low-quota species (Hatcher, 2017). For example, a recent paper by Mortensen et. al (2018) identified two species within the North Sea demersal trawl fishery, Atlantic Cod (Gadus morhua) and Saithe (Pollachius virens) as potential limiting species within the Monkfish (Lophius piscatorius) and Hake (Merluccius merluccius) fisheries.
The majority of fisheries around the world are not 100% monitored but those fisheries that are, allow fishers to be held individually accountable for each and every fish they catch, whether retained or discarded (Mawani, 2009). Fishers in 100% monitored quota systems have a high incentive to avoid catching low-productivity, low-quota species (Branch et al., 2006, 2005; Branch & Hilborn, 2008), and this may strongly influence their choice of fishing location. This was evident in the B.C. trawl fishery where skippers were shown to be avoiding low quota rockfish species Rougheye (Sebastes aleutianus), Shortraker (Sebastes borealis), and Yelloweye that shared the same fishing grounds as target species of sole, flounders, Pacific Cod (Gadus microcephalus), Pacific Hake (Merluccius productus) and other species (Branch & Hilborn 2008). Low quota, low productivity species are often termed ‘choke’, ‘weak’ or ‘pinch point’ species (Condie et al., 2014; Forrest, 2008; Hatcher, 2014, 2017; Mortensen et al., 2018; Plet-Hansen et al., 2014, 2014; Reeves & Davie, 2017; Schroepe, 2010). Leasing enough quota for choke species to enable fishing for target species may become difficult if fishers are not able to adjust their fishing strategies to successfully avoid choke species (Hatcher, 2017; Schroepe, 2010). Choke species can also limit skippers’ spatial fishing options as exploratory fishing strategies, i.e., setting gear in new areas where species composition is unknown is risky. For example, encountering a large patch of a choke species may use up a significant proportion of a skipper’s annual quota and limit their fishing opportunities for the rest of the year.

Choke species in recent years have been area subject of increased fisheries science interest (Mortensen et al., 2018; Schroepe, 2010). As early as 2008, at the twenty-eighth session of the COFI, discards were an “issue of major concern” (FAO, 2011c). The FAO responded to calls for the development of international guidelines on bycatch management and reduction of discards in 2011 (FAO, 2011b). In 2015 a study commissioned by PECH defined choke species as:

“A choke species is a species for which the available quota is exhausted (long) before the quotas are exhausted of (some of) the other species that are caught together in a (mixed) fishery” (Zimmermann et al., 2015, p. 17)

Schroepe (2010) described choke species as “troubled species” with low quota allocation. At the date of publication of this thesis there has been no set of criteria established for the definition of a choke species. This is an important concept within the realm of sustainable
multispecies management, especially with the rise in discard bans in fisheries around the world, such as the European Union’s Common Fisheries Policy EU-wide ban on discards, effective 1st January 2016 (European Union, 2016; European Union Common Fisheries Policy Landing Obligation Regulations, 2015) and the retention obligation for select species, including rockfishes, in the B.C. integrated groundfish fishery (DFO, 2007).

I propose four criteria for defining choke species, which were condensed from a review of the scientific literature (Batsleer et al., 2013; Baudron & Fernandes, 2015; Branch, 2006; Condie et al., 2014; European Union, 2016; FAO, 2011b, 2011c, Hatcher, 2014, 2017; Kelleher, 2005; Mortensen et al., 2018; Ono et al., 2013; Pascoe, 1997; Plet-Hansen et al., 2014; Reeves & Davie, 2017; Schroepe, 2010; Sigurðardóttir et al., 2015; Ulrich, Reeves, Vermard, Holmes, & Vanhee, 2011; Zimmermann et al., 2015). Choke species are here defined as:

1) Species that have a TAC allocations within a quota managed fishery; AND
2) There is a discard ban in place for the species that is enforced by a comprehensive at sea monitoring program; AND
3) The species in question is present in similar spatial and temporal habitat as target species (or other high value species); AND
4) A limit on the species quota restricts fishers’ ability to harvest target species where habitat overlaps.

2.7 Key Species within the British Columbia Hook and Line Pacific Halibut Fishery

Halibut are one of the most valuable commercial groundfish species on the coast (DFO, 2017). Yelloweye is designated as a species of ‘Special Concern’ by COSEWIC and is frequently encountered concurrently with Halibut (Department of Fisheries and Oceans, 2015; Species at Risk Act, SC 2011, c. 29) Basic biological characteristic and habitats are described in the following section.
2.7.1 Pacific Halibut (*Hippoglossus stenolepis*)

*Figure 1: Pacific Halibut (*Hippoglossus stenolepis*) (DFO, 2000a)*

Pacific Halibut is the largest flatfish species on the Pacific coast, with a maximum-recorded length of 267 cm and maximum weight of over 300 kg (Loher & Blood, 2009; Love, 2011; Mecklenburg, Mecklenburg, & Thorsteinson, 2002). Found in waters off the coast of Japan, Russia, United States and Canada down to the northern part of California, Halibut have been recorded in depths up to 1100 m but are commonly found in depths of 27-274 m, and often down to 500 m at certain times of the year (Clark & Hare, 2002; Love, 2011; Mecklenburg et al., 2002). Spawning occurs during winter months in deep waters offshore and along the continental shelf break (Loher, 2008; St. Pierre, 1984). Seasonal migration patterns have been recorded through archival tagging experiments, which have determined that Halibut inhabit deeper depths in winter and spring and move up onto the shallower continental shelf in summer months to feed (Webster, Clark, Leaman, & Forsberg, 2013; Clark & Hare, 2002; IPHC Secretariat, 1987; Loher, 2011; St. Pierre, 1984). Recent tagging research has suggested that mature Halibut annually return to the same feeding grounds in the summer months (Loher, 2008). Inter-annual ontogenetic migration also occurs, following the Halibut’s lifecycle from larvae, which generally are advected north-west to western Alaska with prevailing currents, followed by an ongoing later south-eastern migration towards B.C., Washington, Oregon and California by swimming juveniles and then adults (International Pacific Halibut Commission, 2011).

2.7.2 Yelloweye Rockfish (*Sebastes ruberrimus*)
Yelloweye Rockfish (referred to as Yelloweye from hereon) are one of the largest of the 35 rockfish species present on the Pacific coast and are found from the Aleutian Islands to northern Baja California in waters from 19 – 251 m (COSEWIC, 2008; Yamanaka, Withler, & Miller, 2000). Yelloweye are also one of the longest lived species, with many having a lifespan of at least 118 years but perhaps reaching 147 years old (Love, 2011). Yelloweye exhibit high site fidelity and are typically sedentary, preferring complex, high relief rocky substrate with hiding places (DFO, 2015b; Hannah & Rankin, 2011; Love, Yoklavich, & Thorsteinson, 2002; Richards, 1986). Similar to most rockfish species, Yelloweye have a slow maturation rate and are therefore likely to be less productive than other groundfish species (DFO, 2015b; Siegle, Taylor, Miller, Withler, & Yamanaka, 2013).

2.8 Groundfish Hook and Line Fishery History

Commercial longline vessels have been actively fishing for Halibut and other groundfish species since the late 1880s (Jones & Bixby, 2003). However, long before then, the First Nations People all along the West Coast of Canada, Oregon and Alaska, regularly caught Halibut and Yelloweye (Love, 2011). Traditionally, in both First Nations and commercial fisheries, Halibut has been caught using hook and line gear technology (Casey et. al, 1995, International Pacific Halibut Commission, 2014), although incidental catches of Halibut and Yelloweye occur in other groundfish sectors such as Sablefish, Rockfish, Lingcod and the bottom trawl sectors (Love, 2011; IPHC Secretariat, 1987).

One of the main historical and present day groundfish fishing grounds in B.C. is the Hecate Strait, which is covered by Groundfish management Area 5A, 5B and 5C (Figure 3). Areas 5D and 5E further north are also popular fishing grounds today. Targeted Halibut fishing was first done in Hecate Strait from repurposed riverboats in 1892 (Thompson & Freeman, 1930, p. 33). The smaller riverboats had to be towed out to sea from the harbour by a larger
vessel, which would stow their catch and at the end of the trip, tow them back to harbour (International Pacific Halibut Commission, 2014). Stackable dories were later introduced allowing many more boats to be brought out to the fishing grounds, with the large mother vessels traveling first under sail and later under steam (Love, 2011, Thompson & Freeman, 1930). Although fishing technologies such as mechanized hauling gear and sounding equipment have evolved since the early 20th century, fish are still caught on hand-baited hooks, cleaned by deckhands and stowed below deck in ice. The hook and line fishery uses either ‘snap gear’ (hooks attached to a snap which can be put on and taken off ground line when setting and hauling) or ‘fixed gear’ (hooks which are permanently affixed to the ground line). The ground line is measured in 183 m sections called ‘skates’ which make up a ‘set’ or a ‘setline’. Each set, when deployed, is independent of the vessel, with anchored ends attached to a buoy and a flagpole so fishers can easily pick up the ends to begin hauling back.

The developments in mechanized technology for vessels and fishing gear in the 1900s allowed for an increase in fishing intensity and expansion into deeper, more remote fishing grounds (Thompson & Freeman, 1930). Declining catches and the growing concern over Halibut stock biomass prompted fishers from both Canada and the US to request their governments begin an international Halibut management process (Jones & Bixby, 2003). As fishing rights of the time had no international boundary restrictions, the Canada/USA fleet was integrated and it was determined that management had to be under treaty between the two countries (International Pacific Halibut Commission, 2014).

The International Fisheries Commission (today the International Pacific Halibut Commission (IPHC) was formed through the signing of a convention between Canada and the United States in 1923, ratified in 1924 (Jones & Bixby, 2003, International Pacific Halibut Commission, 2014). This represented Canada’s first independent international treaty as a nation. The first management measure was temporal, closing the fishery in the winter months (Thompson & Freeman, 1930). This closure was aimed at protecting spawning areas identified at the time in Alaska, but also served to deal with marketing issues and fish quality during these months (Jones & Bixby, 2003). It became evident that further management was required to protect the stock as catch rates declined and in 1932 catch limits were put in place (International Pacific Halibut Commission, 2014, p. 5). To avoid exceeding the catch limits, shorter and shorter fishing seasons became necessary. In
1975, the fishing season was 125 days, by 1985 the fishing season had shrunk to 25 days and, in 1990, the B.C fleet had less than six days to catch their fish (Chu, 2009). Boats became bigger and more powerful in order to get to the grounds first, crew fished around the clock and bycatch discards were high in order to make room for the more valuable Halibut in the hold (Jones & Bixby, 2003). At times, the derby openings occurred during dangerous weather patterns. On one opening, strong winds and high seas claimed the lives of a number of fishermen and their vessels (Jones & Bixby, 2003). The economics of fishing also suffered during this time, creating a series of “boom and bust” Halibut markets (Casey et. al., 1995). Processing plants couldn’t deal with the millions of pounds arriving in port in such a short span of time, resulting in low product quality. Fresh product was only available to restaurants and grocery stores for a few weeks of the year and the majority had to be frozen to deal with such large quantities, which resulted in lower prices for the fishing fleet and processors (Jones & Bixby, 2003). In 1991 at the behest of Halibut fishers, the Canadian government implemented the Individual Vessel Quota (IVQ) program for the Canadian portion of the hook and line groundfish fishery to help mitigate some of the problems with the derby-style fishery. Under the IVQ system, quota was linked to the vessel, not the individual skipper. This was the beginning of a process which, in the first few years, increased the safety of fishers, doubled the price of fish, increased quality of the fish product for consumers, and produced less wastage on the fishing grounds (Casey et al., 1995). The bottom trawl sector of B.C.’s groundfish fisheries adopted a monitoring program in the early 1990s for all bottom-trawl trips and all landed catches, and in 1997 they adopted the IVQ system and 100% at-sea observer coverage combined with 100% dockside monitoring (Jones & Bixby, 2003; Wallace et al., 2015). At the time, this initiative was unique, not necessarily only because it was an innovative solution to unsustainable harvesting techniques but because it was minimally driven by the Canadian government and “almost wholly designed by the [fishing] industry” (Casey et al., 1995) who saw the need for change.

As the millennium approached, it became evident further measures were needed to protect B.C.’s multispecies groundfish fisheries (Heifetz, 2007). The Canadian Federal and B.C. Provincial governments and the groundfish fishing industry formed the Commercial Groundfish Integrated Advisory Committee (CGiC) in 2003 to address rockfish bycatch concerns within the groundfish fleets and to try to find more progressive fisheries
management tools to address emerging problems in the fishery (Casey et.al., 1995; Department of Fisheries and Oceans Canada, 2013; Heifetz, 2007, p. 353). The CGIC membership included representatives from commercial fisheries, the Marine Conservation Caucus (representing environmental nongovernmental organizations), Federal and Provincial governments, coastal communities, the B.C. Aboriginal Fisheries Commission and the Sports Fish Advisory Board (Heifetz, 2007). Inefficiencies and wastage were significant concerns as target-species encounters overlapped between the seven separate commercial groundfish fleets, each having their own operational, temporal and spatial complexities (Mawani, 2009). Each skipper was required by conditions of licence, to discard their incidental catch (bycatch) which was often the target species of another groundfish fleet (Jones & Bixby, 2003; Mawani, 2009, p. 7). Discard mortality associated with the discards was high for many species; especially rockfish whose discard mortality rates approach 100% due to barotrauma (Parker et al., 2000). This was detrimental to all fishers from all sectors (Jones & Bixby, 2003; Mawani, 2009). TAC limits were regularly exceeded because skippers were not required to report discards and the partial coverage observer program was “known to be biased because ‘observed’ skippers would alter their behaviour” (Heifetz, 2007). Skippers were concerned the true harvest was being underestimated as a result of under-reporting, and researchers did not have access to validated data under a reliable monitoring program in order to calculate stock assessment or IVQ accurately (Heifetz, 2007, p. 353). All parties of the CGIC recognized the need for significant improvements to management.

Pacific Canada’s integrated groundfish fishery employs three different gear types (hook and line, trawl and trap), and targets 77 commercially valuable species. These fisheries are managed under a single resource management plan, developed collaboratively between the scientific, public and the commercial fishing sectors, known as Commercial Groundfish Integration Program (CGIP) (Sporer, 2017). The pilot project was introduced in 2006 and included: 1) 100% at-sea monitoring; 2) 100% dockside monitoring; 3) individual vessel accountability for all catch, both retained and released; 4) the ability to reallocate (trade) quota among individual vessels to cover non-directed species catch; 5) an ITQ system; and 6) a series of protected Rockfish Conservation Areas (RCA) (Mawani, 2009; Stanley et al., 2015). Species are managed through TAC and ITQs limits set by the Department of Fisheries and Oceans Canada (with recommendations from the IPHC for Pacific Halibut).
In 2010, the successful pilot project was implemented on a permanent basis (Department of Fisheries and Oceans Canada, 2013). Today, a comprehensive ITQ system exists wherein licence holders can temporarily or permanently transfer quota among licences to cover their non-target catch. This has stimulated the evolution of a variety of fishing business strategies that combine quota on different licences. The ITQ system differs from the old IVQ system in that the individual harvester holds the quota whereas with the IVQ system, the quota was held on the vessel making transfers more difficult. The CGIP brought all of the groundfish sectors together under a single management plan, the Integrated Groundfish Management Plan (IFMP). This has allowed groundfish fishers to work together to solve conservation issues, transfer quota and to make fishers responsible for their catch so each fish caught is accounted for and TACs are not exceeded.

All groundfish bottom trawl vessels have carried human observers since 1996. However, 100% at-sea monitoring presents a challenge on smaller longline vessels. In order to enforce retention and prevent illegal discards, an innovative electronic monitoring (EM) system, consisting of two cameras, is now in place on all longline vessels in the B.C. integrated groundfish fishery (Stanley et al., 2015). The cameras, which are triggered to start recording when the hydraulic hauling system activates, record GPS location, date and time, species, size and vessel ID, which is stored on a secured “black box” hard drive in a computer on the vessel. This hard drive is removed upon return to port and audited by an independent monitoring organization, Archipelago Marine Research (Stanley et al., 2015). Skippers are required to keep count of all species encountered, both legal and sublegal sizes in a standardized logbook. When the fish is offloaded in port, an observer is present to count and weigh all species landed as well as tagging each Halibut with a unique bar code. These weights are then deducted from the vessels remaining ITQ. This tagging system was a voluntary initiative, funded and implemented by the commercial fishers so that each fish can be traced. Initially, only 10% of the EM footage is audited, and if the reviewed EM numbers match the logbook, then the logbook counts as the record. If the numbers deviate from the prescribed tolerance limit (set by the Electronic Monitoring Sub Committee of the Commercial Industry Caucus whose members include participants from science, IT, and enforcement groups from within DFO) then the skipper’s footage is audited at the individual skipper’s expense (Mawani, 2009). This system overcomes problems associated with reviewing such large amounts of footage while ensuring
compliance with the regulations (Mawani, 2009). The data generated by this system are comprehensive, accurate and valuable for calculating spatially detailed Catch per Unit Effort (CPUE) (Stanley et al., 2015).

Catch limits have been reduced for several species since integration in response to recent stock assessment results and the findings of COSEWIC. The TACs for two species Bocaccio (*Sebastes paucispinis*) and Yelloweye, have been reduced significantly (DFO, 2017). In 2014, following a stock assessment showing Yelloweye to have a high probability of low biomass (COSEWIC, 2008; DFO, 2015b), the DFO set out a plan for a stepped reduction of the Yelloweye TAC from 287 metric tonnes to a final total TAC of 100 metric tonnes after three years (DFO, 2015a).

In 2017, the Halibut sector had 130 active skippers. There are 19 species for which quota is allocated to the Halibut sector (see Appendix A) but fishers are able to temporarily or permanently lease quota for other species (DFO, 2017). As part of the ITQ system, Canadian groundfish fishers are permitted a “carry-over” of uncaught target and non-directed species from one fishing season to the next (DFO, 2017). Licence holders can carry over 10% of uncaught Halibut and up to 30% of their allocated non-directed species. The equivalent weight of 10% for Halibut and 30% for other species will be added to the subsequent year’s licence but any amount exceeding that number will be forgone (Fisheries and Oceans Canada, 2017). This is important for understanding the effects of any quota reductions, because there will be a lag-effect due to the ability of fishers to carry over some quota from the previous year.

### 2.9 Stakeholder Engagement and the Value of Combining Quantitative and Qualitative Research Methods

Hilborn and Walters (1992) described fisheries as “dynamic systems that involve fish, fishermen, managers and the assorted biological, economic and social factors that affect them.” (p. 141). In short, there is a social aspect to fisheries that is often overlooked by fisheries researchers (Salas & Gaertner, 2004). Through incorporating qualitative research methods, researchers can gain access to a wealth of knowledge held by fishers, which may
not be initially apparent in statistical data analysis. Mixed method research (research that incorporates both quantitative and qualitative methods) over the past 20 years has seen increasing interest in the fisheries research community (Onwuegbuzie, Gerber, & Schamroth Abrams, 2017). This thesis has been designed to integrate the quantitative data analysis of fishers’ log book data through a variety of statistical methods and to triangulate this data with interview data from individual active fishers’ from the B.C. Halibut commercial hook and line fleet. I employ Denzin’s (1978) theory of ‘Methodological Triangulation’ whereby I employ the “use of multiple methods to study a single problem” (as cited in Teddlie & Tashakkori, 2009) (Patton, 2002, p. 247). Incorporating qualitative research methods in fisheries research has limitations, as stakeholders’ perspectives and opinions can be greatly divergent, each skipper has their own unique history and experiences, yet this subjective data can be valuable when researching fishers’ behaviour on the fishing grounds (Pascoe, Bustamante, Wilcox, & Gibbs, 2009; Salas & Gaertner, 2004). This is especially important for understanding the effects of management measures.
3 Methods

3.1 Study Location

Unless otherwise stated, all analyses were limited to DFO Groundfish Management Areas 5A, 5B, 5C, 5D, 5E (collectively, Area 5; Figure 3), as the majority of Halibut commercial hook and line fishing activity takes place within these management areas (Figure 4, Figure 5). Commercial Halibut fishing activity occurs within the 200 nautical mile EEZ. Areas 3 and 4 are not included in the scope of this thesis.
Figure 3: Department of Fisheries and Oceans Canada's Pacific Groundfish Management Area of the coastal waters of British Columbia. Red circle indicates area of study for this analysis, Areas 5A, 5B, 5C, 5D and 5E (Map adapted from (DFO, 2017)).
Figure 4: Line density map indicating changes over time of the setline catch density (kg per square km) of Pacific Halibut caught by the B.C. hook and line commercial fishing fleet for years 2007, 2015 and 2017. Setline frequency for all sets in Area 5 and Area 3 for each year. Setline Catch Density values (1-10) are ten equal groups over which the setline catch density is divided and should be interpreted as relative values. Data with fewer than three vessels per 4 km$^2$ cells are not shown due to Privacy Act restrictions (Privacy Act, 1985). Source: DFO unpublished data.
Figure 5: Line density map indicating changes over time of the setline catch density (kg per square km) of Yelloweye Rockfish caught by the B.C. hook and line commercial fishing fleet for years 2007, 2015 and 2017. Setline Catch Density values (1-10) are ten equal groups over which the setline catch density is divided and should be interpretive as relative values. Data with fewer than three vessels per 4 km² cells are not shown due to Privacy Act restrictions (Privacy Act, 1985). Source: DFO unpublished data.

3.2 Fishery Data

This study focuses on Canada’s Pacific hook and line commercial fishery, specifically the Halibut sector (i.e., L licence category). While this is a multispecies fishery, key species include Pacific Halibut and Yelloweye Rockfish. During the course of this study, I was an employee of the Department of Fisheries and Oceans (DFO) and was given security clearance to use high-resolution spatial logbook data from the Canadian Integrated Groundfish Fishery from 2006 to 2017, inclusive. Skipper ID and Vessel ID were encrypted for my use in order to avoid any potential bias or conflicts. Access was also granted to data from the groundfish biology database (GFBIO), which contains fishery-independent scientific survey data collected by DFO and the IPHC.

Logbook and survey data used in this analysis included: start and end latitude and longitude positions of setlines; dates; species catch information from the top 19 species managed under the ITQ system; vessel identification numbers and skipper identification
numbers (encrypted for anonymity); set depth; set length; season; and other key fields collected from skippers’ logbooks, e-logbooks and dockside validation data stored in the Groundfish Fisheries Operations System (GFFOS) database. GFFOS data relevant to the present study was consolidated into a separate sub-database (HALIBUT_FE) and sourced for all further analysis. Refer to Appendix D (FOS descriptions) for data definitions with corresponding measurement units.

All maps were produced in compliance with the Privacy Act (Privacy Act, 1985) which means that data can only be displayed for grid cells containing three or more vessels. Maps for publication in this thesis that contain commercial data are created with defined buffers around each individual set. Grids with buffered sets from three or more vessels intersecting the grid (in a single year) are included in this analysis. Maps throughout this thesis were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license.

3.3 Fishery Independent Scientific Survey Data

There are two fisheries independent scientific surveys that are relevant to this thesis: 1) the International Pacific Halibut Commission Setline Survey, a fixed station survey, which has been annually sampling in US and Canadian waters since 1967 (with a break from 1987-1992); and 2) the Outside Area Hard Bottom Longline Hook (OAHBLH) which samples near-shore waters in B.C., using a depth stratified, random design.

3.3.1 IPHC Annual Setline Survey

The IPHC conducts annual fishery-independent setline surveys to collect standardized data for the Pacific Halibut stock assessment. Data from the IPHC Setline Survey provide an annual coast wide relative abundance index and distributional information for Pacific Halibut (in the US and Canada), and rockfishes and other species in B.C. (DFO, 2017). The survey covers regions from the Bering Sea to northern California, including Canadian waters (IPHC Secretariat 2017). The areas are sampled on a grid and spaced regularly at 10 nautical miles (nm) (Figure 6). The survey uses longline gear, with standardized hook-spacing, bait and soak times throughout the whole area of coverage (IPHC Secretariat 2017). Catch are sampled for biological data for Halibut and other species, to monitor biomass, growth rate, sexual maturity, and mortality rates (IPHC Secretariat, 2017). In
British Columbia, the Pacific Halibut Management Association (PHMA) (a fishing industry association) provides an extra biologist, through a collaborative agreement, to collect biological data from rockfishes that are caught (including Yelloweye). Annual surveys are restricted to the summer months (June-August). Data are uploaded to DFO’s GFBIO database and include species catch, date, set length, set depth, season and vessel information (See Appendix D).

**Figure 6:** IPHC Scientific Setline Survey design in B.C.. Red dots indicate actual areas where setlines are sampled on a 10 nautical mile grid using standardized bait and gear from 2007-2017.
3.3.2 Depth stratified, random design longline research survey

In August 2006 the DFO, in collaboration with the PHMA, introduced OAHLBH survey (Figure 7) (Rutherford, 2016). This survey was designed to investigate stock dynamics of inshore rockfish populations (including Yelloweye) by employing standardized longline gear to collect biological samples and to provide catch rates of species encountered (“Depth Stratified Random Design Longline Research Survey,” 2009). Northern and Southern areas off B.C. are sampled alternately each year by three charter vessels, which have from the beginning of August until mid September to complete their assigned sampling stations (“Depth Stratified Random Design Longline Research Survey,” 2009). DFO assigns each charter vessel a set of randomly-selected 2 km × 2 km survey area locations (blocks) that have been identified as hard-bottom areas. Average estimated depth of each block is calculated and a random selection of blocks from each depth strata is selected for sampling. Within each selected block, skippers are required to select a suitable fishing location to deploy their gear at a specified depth (“Depth Stratified Random Design Longline Research Survey,” 2009). Data are uploaded to DFO’s GFBIO database and include species catch, date, set length, set depth, season and vessel information (Appendix D).
Figure 7: OAHBLH scientific rockfish stock assessment survey 2006-2016. Data not available yet for 2017.
3.4 Data Exploration

3.4.1 Licence scope

The commercial Halibut sector, or L licence sector, is part of the B.C. integrated groundfish fishery, comprised of seven different commercial fleets, which use three different gear types (trawl, trap and hook and line). While a vessel is engaged in Halibut fishing, it may also hail out on other licences such as Sablefish (K licence) or Rockfish (ZN licence) under the IFMP. This has shaped how some fishers approach Halibut fishing as fishers can now do ‘combo-trips’ in which they hail out on multiple licences. These factors can complicate interpretation of the data so, for the purpose of this study, the analysis was limited to those fishers who only hailed out on an L licence and their corresponding fishing sets.

The B.C. Halibut commercial fishery has opened in March and closed in November since 2007. Preliminary data analysis began by investigating the proportion of sets made throughout the year, overall management areas, to identify periods of time during the year when the greatest proportion of fishing effort takes place. Under the groundfish IFMP (DFO, 2016; DFO, 2017), licence holders may carry over up to 30% of unfished quota to the next fishing season. Detailed information about the amounts of quota carried over was not available and, therefore, for the purposes of this analysis, carry-over was not accounted for in the calculation of annual TACs. Due to the complex nature of the ITQ allocation scheme, quota caught on an L licence may have been leased from another sector or quota may be allocated to another sector. Consequently, there may be a slight mismatch between TACs published in the IFMPs and those used in this study, which should be considered as trends. This analysis used the database field Landed_round_kg (See Appendix D) for the calculation of all figures unless otherwise specified.

3.4.2 Spatial scope and fishing effort distribution

Spatial fishing effort distribution was examined using catch density heat maps generated using ESRI ArcGIS 10.4.1 software in Management Areas 3 and 5. Heat maps were generated with a radius of 8 km around grid cells of 4 km$^2$ using the Jenks optimization method, which was developed by cartographer George Jenks and is sometimes referred to
as the ‘goodness of variance fit’ (“Jenk’s Optimization,” n.d.). It is a clustering tool within ArcGIS that divides data into classes to determine the best arrangement according to data distribution (ESRI, 2017; Jenks, 1967). This tool “seeks to reduce variance within groups and maximize variance between groups” (“Jenk’s Optimization,” n.d.). In this study, the tool clustered setline data into groups based on their relative distance between each other.

Number of longline sets in the L-licence category, number of active vessels and active skippers were plotted from 2007-2017 to determine trends within the Halibut fleet coastwide (all areas). Halibut sets made while hailed out on other groundfish licences (which is permitted by licence conditions) were not included in this analysis. Total coastwide Halibut TAC allocated to the B.C. hook and line commercial fishing fleet was also plotted over time.

Yelloweye Rockfish is proposed as a choke species for the Halibut hook and line fishery. Throughout this thesis, evidence to support Yelloweye being a choke species was evaluated, using the four novel criteria proposed in Section 2.6. Criteria 1 and 2 state that the species should be caught in a TAC managed fishery and discard bans should be in place and enforced for the species, both of which are satisfied for Yelloweye. Criteria 3 concerns species spatial overlap and is examined in the next section. To evaluate Criteria 4, i.e., to determine whether Yelloweye quota has restricted fishing opportunities for Halibut, Yelloweye TAC (both coastwide and for the L licence category) was plotted over time to show trends from 2007-2017. The mean annual Yelloweye catch was also plotted over time to compare the TAC trends to the realised catch.

In order to establish if Yelloweye Rockfish are present on Halibut fishing grounds and likely to be encountered by fishers, OAHBLH depth stratified survey data were used to examine trends in the density of Yelloweye encountered in each management area. Using fisheries independent survey data ensures that the commercial data bias (potential ability to selectively target or avoid species) is reduced. The proportion of annual Yelloweye TAC was examined across Area 5 management areas to investigate possible spatial patterns in Yelloweye encounters.
3.4.3 Inter-annual scope and intra-annual seasonal patterns

Spatial commercial hook and line catch data are available from 2006, the same year the IFMP pilot project was introduced, but as 2006 was a pilot year, it is not considered representative of full implementation of the integrated fishery and electronic monitoring system. Enforcement, full program coverage and regulation details were still being refined in 2006 (DFO, 2006b). 2007 was therefore chosen as the base year of the data. Data from 2007 to the most current available data at the time of writing (December, 2017), unless otherwise stated was used. 2007-2017 years were used for the bulk of the analyses presented here, following the recommendations of active fishers, to incorporate as many spatio-temporal trends as possible and the entire time period since integration.

Seasonal fishing patterns were identified to establish characteristics of the fishery throughout the year and to calculate when most fishing takes place. Seasons were defined as spring (March-April), summer (May-August), and combined fall & winter (September-November), through examination of noteworthy differences in fishing strategies such as average setline depth. Proportion of all landings was measured by season as well as proportion of sets by season. Patterns in annual number of sets by season were also plotted.

Yelloweye landings were examined separately from Halibut to determine seasonal patterns in catches of this species. Total Yelloweye landings by year and by season were calculated as well as the proportion of annual Yelloweye TAC from 2007-2017. For analysis of spatial fishing shifts associated with the reduction of Yelloweye quota, 2007-2015 are considered “prior” years (before the 2016 Yelloweye quota reduction), for comparison with “post” years, 2016-2017. Proportion of landed Yelloweye was also examined across sub areas within Area 5. For sensitivity analysis, 2009-2015, 2012-2015 and 2014-2015 were also used as ‘prior’ years for key figures to investigate the impact of different sampling scenarios on detected prior years verses post years’ fishing patterns. 2009-2015 was chosen because of a reduction in Halibut TAC allocation (by 40% Figure 10), 2012-2015 was chosen because the Halibut TAC stabilized during those years until 2017 (between 2627 tonnes and 2845 Figure 10), and 2014-2015 was chosen because it offers an equal prior and post year comparison (two years in both prior and post). While this sensitivity analysis was performed with the effects of Halibut TAC reductions in mind, as
it is an important factor to consider when examining fishing behaviour, this thesis’ focus is on the potential effects of Yelloweye TAC reduction has had on the fishery.

### 3.5 Depth Analyses

To evaluate Criteria 3 for choke species (Section 2.6), which concerns species spatial overlap, the IPHC scientific survey data were examined using histograms of the depth encounters to quantify the depth ranges at which Halibut and Yelloweye overlap. Seasonal depth shifts were not examined because the annual IPHC survey is conducted only in the summer months. Depth ranges were not examined from the OAHBLH survey because this survey is designed as a depth-stratified survey to sample potential rockfish habitat (skippers are instructed to target rockfish habitat). Therefore it is not representative of both Halibut and Yelloweye depth distributions. The gear used in the OAHBLH survey also uses smaller hooks than those are optimised to catch Halibut, which are used in the commercial fleet and IPHC survey.

Depth histograms of commercial fishing data were also plotted to show overlap of Halibut and Yelloweye, both inter-annually seasonally. Spring and summer seasons were analysed for maximum, minimum and mean encounters for both Halibut and Yelloweye. Overlap in the depth profile for both species encountered was calculated. To examine seasonal changes in Halibut fishing depths, weekly and monthly setline depths were plotted from 2007-2017.

### 3.6 Location of Fishing Grounds

#### 3.6.1 Fishing locations prior and post- Yelloweye quota reduction

To evaluate whether the fleet has changed its depth distribution since the reduction in Yelloweye quota, commercial Halibut sets for Area 5 were plotted by depth over time to determine seasonal mean and median depths. Spring sets and summer sets were plotted separately. To explore whether trends were different in sets that did and did not encounter Yelloweye, the data were filtered to: (i) exclude any sets that caught Yelloweye and (ii)
include only sets that caught Yelloweye. Mean and median depths were compared to determine annual trends.

The purpose of this GIS-based analysis was to gain preliminary insights into whether there had been any spatial fishing shifts associated with the reduction of Yelloweye quota. Because Yelloweye quota was first reduced in 2016, the years 2007-2015 are considered prior years, for comparison with post years 2016-2017. For the purposes of this section prior fishing grounds are areas fished before the 2015 Yelloweye TAC reduction and post fishing grounds are areas fished after the Yelloweye reductions. They are not exclusive and in some cases overlap. For the purposes of this particular analysis, Halibut fleet “fishing grounds” are defined as clusters of “effective” longline fishing sets that aggregate in the same geographic area over time. Clusters of longlines can be fished by multiple vessels.

An effective fishing set is characterized by the area over which the gear is assumed to move during soak time. Generation of these effective longline-fishing areas was achieved by filtering the database for set lines with valid lengths (less than 4 km), then applying a geodesic buffer of 500 metres around each. The buffer of 500 meters was based on expert knowledge from the commercial fleet (see Section 4.6). Although this was the average reported, distance between sets differs with fishing strategy, bottom feature characteristics and tidal factors among many other variables. Interview subjects reported leaving an average distance of 3 cables (0.56 km) between sets so that they do not snarl together.

Using ArcGIS © software (ESRI, 2017), orthogonal aggregation of effective longline fishing sets within boundaries of 500 metres was performed to reveal clusters of fishing grounds for the summer and spring seasons, for 2007 through 2017. To comply with the Privacy Act, only clusters that had a minimum size of 10 km² and contained three or more vessels were shown (Privacy Act, 1985).

### 3.7 TAC and Catch ratios

This part of the analysis follows the methods of Branch and Hilborn (2008), developed for their analysis of changes in fishing behaviour in the B.C. groundfish trawl fishery after the introduction of ITQs with 100% observer coverage in 1997. TAC ratios and Catch ratios
were calculated to test whether the fleet was able to adjust its catch to achieve TAC reductions for Yelloweye.

### 3.7.1 TAC Ratios

TAC Ratios measure changes made to the Yelloweye TAC in post years (2016-2017) compared to prior years (2007-2015). The TAC Ratio, $R_T$, is given by:

$$R_T = \frac{2 \tilde{T}_{2016-2017}}{\tilde{T}_{2016-2017} + \tilde{T}_{2007-2015}} - 1 \quad \text{(Eq. 1)}$$

(*sensu* Branch and Hilborn, 2008), where $\tilde{T}_{2007-2015}$ is the mean annual Yelloweye TAC from 2007-2015, $\tilde{T}_{2016-2017}$ is the mean annual TAC from 2016-2017 and $-1 \leq R_T \leq 1$. A negative value of $R_T$ indicates that the mean TAC was reduced post-2015, while a positive ratio indicates mean TAC was increased. Consequentially a negative ratio indicates increased incentive to avoid Yelloweye, whereas a positive ratio indicates an incentive to target Yelloweye. Therefore TAC ratios are an indication whether skippers are likely to target or avoid species (Branch & Hilborn, 2008), i.e., species can be classified into those that should be preferentially targeted ($R_T > 0$) and those that should be preferentially avoided ($R_T < 0$) (Branch & Hilborn, 2008).

Equation 1 is an example of a bounded ratio (bounded between -1 and 1). Bounded ratios are useful in this application because the larger quantity of sets in “prior” years (2007-2015) are not given more weight than “post” years (2016-2017), allowing direct comparison between the ratios for each time period (Branch and Hilborn, 2008).

### 3.7.2 Catch Ratios

While TAC ratios indicate incentives for targeting or avoiding certain species, the catch ratios indicate the fleet’s ability to comply with catch limits. For example, if both TAC ratios and catch ratios are negative, this would indicate avoidance of Yelloweye.

The Catch Ratio, $R_C$, was calculated to measure catches in prior years to catches in post years. The Catch Ratio, $R_C$, is given by:

$$R_C = \frac{2 \tilde{C}_{2016-2017}}{\tilde{C}_{2016-2017} + \tilde{C}_{2007-2015}} - 1 \quad \text{(Eq. 2)}$$
(sensu Branch and Hilborn, 2008) where $\bar{C}_{2007-2015}$ is the mean annual catch from 2007-2015, $\bar{C}_{2016-2017}$ is the mean annual catch from 2016-2017 and $-1 \leq R_C \leq 1$. Positive values indicate that mean catches increased in post years, whereas negative values occur if mean catches decreased in post years.

### 3.8 Cluster Analysis to Identify Fishing Opportunities

The previous sections examined annual and seasonal trends across the entire Halibut fleet. To evaluate whether Yelloweye avoidance was likely to be contributing to changes in fishing patterns, it was necessary to analyse the behaviour of individual skippers. This was done through application of methods developed by Branch et al. (2005) and Branch and Hilborn (2008). The method involves clustering fishing sets to identify “fishing opportunities”, which are defined as repeat fishing locations particular to an individual skipper, then tracking their use over time (Branch et al. 2005). Fishers who revisit fishing opportunities inter- or intra annually can predict, to a certain extent, what might be encountered and therefore return to areas in which they encounter an assemblage of fish that is matches their fishing strategies (Branch & Hilborn, 2008). Areas that fishers avoid or abandon altogether can be therefore predicted to have an “undesirable” assemblage of species, in terms of the combination of species quota held.

The Branch et al. (2005) definition of a trawl fishing opportunity was adapted for the Halibut fleet to be a small area over which a skipper of a vessel frequently sets their fishing hook and line gear. This area is usually determined by the bottom features (e.g., substrate type such as rocky or sandy bottom, depth or slope) and is unique to each skipper and their personal fishing strategies and experiences. Fishing strategies may take into account tidal cycles, seasonal migration patterns of species, skippers’ historical experience of the area and/or distance to port among many other motivating variables (see Section 4.6). The advantage of identifying individual skippers’ fishing opportunities for analysis instead of using a traditional grid system is that it ensures fishing behaviours can be analysed on very fine spatial scales. Also, using fishing opportunities ensures only the area fished is examined. The grid system may be employed on too large a scale and group multiple
fishing opportunities together, or on a scale too small to include the entirety of a set, dividing up a single set into multiple cells. I am unaware of any studies that have adapted the Branch et al. (2005) cluster analysis to the B.C. Halibut hook and line fishery.

3.8.1 Clustering methods

The statistical clustering approach adapted from Branch et al. (2005) was applied to individual skippers’ logbook data. The method uses the combined Euclidean distance between a given pair of longline sets start and end positions (latitude and longitude of each position) to define clusters of sets.

The clustering method followed the following steps, implemented in the R statistical language (R Core Team, 2017). First, longline sets were re-oriented where necessary, by flipping the start and end points of southerly running sets so that all start positions were aligned, allowing sets in the same orientation but running in opposite directions to be clustered into the same fishing opportunity, using proximity of start positions. Sets were then clustered together using an adaptation of the methods used by Branch et al. (2005), which applies hierarchical agglomerative clustering based on the Euclidean distances between start and end positions of each setline (for R code, see Branch et al., 2005, their Appendix A). Once clustering was complete, it was necessary to define a “cut point” on the resulting cluster tree to determine which clusters should be grouped into fishing opportunities. A cut point is the level on the cluster tree where the sets are determined to be clustered together forming fishing opportunities (Figure 8). A larger cut point (or a larger distance between sets) will result in fewer fishing opportunities until finally there is one single fishing opportunity (when all sets are clustered together). A smaller cut point will result in many fishing opportunities and possibly many single sets being defined as a fishing opportunity. It is important to determine an appropriate cut point for the analysis so that groups of sets in similar geographical areas will be grouped together while ‘exploratory sets’ or single sets made in areas far away from others will not be grouped.
Figure 8: Fishing Opportunities cluster example with multiple sets (along the x axis) illustrating the fishing opportunities obtained with a cut point of 0.23 km (red line). Distance between each set (km) is on the y-axis. Clusters above the cut point are considered unique fishing opportunities (adapted from (Branch et al., 2005). In this illustrative example there are 17 fishing opportunities, which can be calculated from the number of vertical lines intersected by the red line.

While choice of a cut point is always somewhat subjective, Branch et al. (2005) suggested using median distance between trawls. In this study, the cut point was calculated as a function of median distance (Euclidean distance) between sets for the top 25% of skippers (ranked by total annual average weight in kg of landed Halibut). This deviated slightly from the approach of Branch et al. (2005), who calculated their cut point (0.15 km) based on median speed and trawl duration using data from the top 70 vessels, as determined by number of trawls. In this analysis, number of sets was not considered sufficient to define the top skippers, as this would eliminate some skippers who were most efficient at catching Halibut. Similarly, for tractability, fishing opportunities were only calculated for these top 80 skippers.

Branch and Hilborn (2005) used 15 sets as the minimum per fishing opportunity for their subsequent analyses of the groundfish bottom trawl fleet. In the present study, five sets were chosen as minimum because the hook and line fleet in recent years have been able to catch their quotas by deploying fewer sets compared to 2007 (See Section 4.1.1).
Following clustering, the resulting “fishing opportunities” were then converted into colour-coded polygons and overlaid onto coastal charts.

Seasonal attributes of the top 80 skippers and their fishing opportunities were plotted to examine annual and seasonal trends. To look for seasonal differences in prior and post years, for each individual skipper, the number of sets in each season (spring and summer) across all fishing opportunities was plotted. To examine seasonal differences among fishing opportunities, the number of sets in each season (spring and summer) per fishing opportunity was plotted for each skipper. Similarly, the proportion of sets in each season (spring and summer) per fishing opportunity was also plotted. These figures were compared to identify seasonal patterns across the top 80 skippers.

### 3.8.1 Utilization Ratios

The previous section identified fishing opportunities by clustering individual skippers’ longline sets. Continuing this approach, “utilization ratios” can then be used to measure how fishing opportunities were utilized before and after Yelloweye TAC reductions.

Utilization ratios were calculated using formulas adapted from Branch and Hilborn (2008), given by

\[ P_{y,i} = \frac{N_{y,i}}{\sum_i N_{y,i}} \]  \hspace{1cm} (Eq. 3)

And \[ R_{U,i} = \frac{2\bar{P}_{2016-2017,i} - \bar{P}_{2007-2015,i} + \bar{P}_{2016-2017,i}}{\bar{P}_{2007-2015,i} + \bar{P}_{2016-2017,i}} - 1 \]  \hspace{1cm} (Eq. 4)

Where \( N_{y,i} \), the number of is sets in year \( y \) (or set of years) in fishing opportunity \( i \). \( P_{y,i} \) is the proportion of sets by an individual vessel conducted in year(s) \( y \) in fishing opportunity \( i \). \( \bar{P}_{2007-2015,i} \) is the mean proportion of sets in fishing opportunity \( i \) in prior years (2007-2015) and \( \bar{P}_{2016-2017,i} \) is the mean proportion of sets in fishing opportunity \( i \) in post years (2016-2017). Like the Catch and TAC ratios (see Section 3.7) utilization ratios are a type of bounded ratio. Utilization ratios measure whether a given vessel increased utilization (i.e., proportion of sets) on a particular fishing opportunity (positive \( R_{U,i} \)), or decreased.
utilization (negative $R_{U,i}$) in post years compared with prior years. New (exploratory) fishing opportunities, where no sets had been deployed in prior years would have a utilization ratio of +1 whereas ‘defunct’ fishing opportunities, which were not fished in post years, would have a utilization ratio of -1 (Branch and Hilborn, 2008).

Number of sets made by the top 80 skippers was plotted from 2007-2017 and compared with the number of fishing opportunities over the same time period to investigate patterns in prior and post years

Utilization ratios were divided into four categories:

- **Category 1**: $R_{U,i} = -1$,
- **Category 2**: $-1 < R_{U,i} \leq 0$,
- **Category 3**: $0 < R_{U,i} < 1$; and
- **Category 4**: $R_{U,i} = 1$.

In order to examine patterns in utilization of fishing opportunities, the proportion of fishing opportunities in each category was plotted across all skippers for both spring and summer seasons. This allowed for visualization of the proportion of fishing opportunities in each category, for spring and summer separately.

To examine species compositions in each category and to help understand the motivations for skippers choosing to fish more or less in each fishing opportunity, for each individual skipper, catch composition (Halibut, Yelloweye and other species) in fishing opportunities was plotted by category as a function of depth. This complex portion of the analysis was done to further understand attributes of fishing opportunities, and what might be the deciding factors (depth or species encountered) for skippers’ choices to increase, decrease or abandon utilization of fishing opportunities. Plotting the catch composition of the fishing opportunities across categories allowed for investigation of the species composition of abandoned, negative and positive fishing opportunities.

To examine seasonal trends behind fishing opportunity utilization and Yelloweye encounters, mean proportion of Yelloweye landed in each of the above categories across the top 80 skippers was calculated. These proportions were calculated for spring and summer separately. The mean proportion of Yelloweye landed in spring was plotted across
categories to examine whether fishing opportunities with negative or abandoned utilization ratios (categories 1 and 2) had a greater mean proportion of Yelloweye. Similarly, this analysis was repeated for Halibut to examine whether positive fishing opportunities (Category 3) had a greater mean proportion of Halibut.

The nonparametric Kruskal-Wallis test was used to test for statistical differences among Categories 1-3, instead of its parametric equivalent (one-way analysis of variance (ANOVA)) because the data were not normally distributed in categories. This is due to the skewed data distribution of species catch records. In some sets, skippers encountered no Yelloweye, while encountering many Yelloweye in others. The null hypothesis in this case would be that the mean proportion of Yelloweye in a category is the same for all categories. A significant result ($P < 0.05$) would suggest that two or more categories have statistically different proportions of Yelloweye, resulting in rejection of the null hypothesis (Teetor, 2011, Dalgaard, 2008). The same analysis was repeated to test for differences in mean proportion of Halibut among utilization categories.

### 3.9 Interviews with Individual Skippers

Fishers’ spatio-temporal behaviour was thoroughly examined in the previous sections using logbook data; further insight into behaviour was only possible through interviews of active fishers. A multiple choice and short answer survey was created to better understand individual fisher’s motivations regarding fishing behaviours (Appendix B). My personal experience within the fishing community made these interviews possible, as participants and I had a previously established rapport. This section of the analysis was designed to provide details not evident in logbooks data and to allow fishers with extensive knowledge of fishing behaviours to participate in this study.

A total of five fishermen were given a survey with multiple choice and short answer questions. Because this was such a small sample size, analytical software was not used; analysis was performed manually. Participants were identified through workshops where volunteers self-nominated and through the snowball sampling method (Bernard, 2006). My personal knowledge and contacts within the fishery contributed to identifying participants for the interviews. Three Interviews were conducted in person using a multiple choice and short answer interview forms and two surveys using the same multiple choice and short
answer interview forms were distributed to active skippers (see Appendix B). Fishermen who agreed to release their personal information (in connection to their data) to me were presented with maps of their fishing data. Conversations, when in-person meetings were possible, were recorded and notes were taken using a tablet so spatial information could be transcribed onto fishermen’s annual and composite maps of fishing effort as well as utilization ratios of fishing opportunities. Consent forms and personal data release forms were signed by each participant (see Appendix B). This participant pool was small due to logistical limitations and while statistical results were not possible, the information gleaned from these interviews helped inform portions of the analyses. Participants were only selected if they were skippers (captains) of vessels, and therefore had the ultimate authority on fishing behaviour choices of that vessel and owned the historical logbook data, in order to ensure data confidentiality (see Section 3.2). Interview audio files and completed survey forms are stored on encrypted drives (paper copies are kept in a secure area) and access limited to staff at the DFO, Pacific Biological Station.

3.9.1 Influences on fishing behaviours

I used Ken Wilber’s Four Quadrant Integral theory model, originally designed to integrate science and religion, and adopted this model to represent the complexities present in the Halibut hook and line fishing fleet (Wilber, 1998). Wilber’s method allows the influencing factors on skippers fishing behaviours to be examined from four combinations of perspectives: the interior, the exterior, the individual and the collective (Wilber, 1998). The results of the interviews and surveys were organized into these four quadrants to illustrate that behaviours are motivated by multi-dimensional factors and that spatio-temporal fishing effort behaviour is a potential result of an accumulation of these factors and not necessarily a single factor.
4 Results

4.1 Data Exploration

4.1.1 Overview of spatial and temporal changes in the fleet

Annual number of fishing sets across the L licence fleet across all areas decreased by 44% between 2007 and 2010. From 2010-2014 there was decrease in number of sets by 20%, and then there was a slight steady increase of 5% in the number of sets until 2017 (Figure 9a). Number of sets (Figure 9a) closely follows the trends of coastwide TAC Halibut allocation over the years (Figure 10), which decreased by 47% between 2007 and 2009, but has remained relatively stable since 2009. The annual number of skippers active in the fleet decreased by 15% from 2007-2009, but has stayed relatively stable since 2009, sitting between 134 and 128 skippers with 128 active skippers in 2017 (Figure 9b), showing similar trends to number of sets and Halibut TAC allocation. The annual number of vessels active in the fleet decreased by 22% from 2007-2011. There were 11 more vessels in 2012 than in 2011. Number of active vessels has increased by 15% since 2014 (Figure 9c).
The Halibut TAC allocation decreased notably between 2007, when a TAC of 5730 tonnes was allocated to the hook and line fleet, and 2008, when the TAC allocation was reduced to 4082 tonnes (Figure 10). There was a further reduction to 3044 tonnes in 2009, after which the Halibut TAC stayed relatively stable until 2017, when the TAC was 2845 tonnes (Figure 10).

Figure 9: a) Annual number of sets for all Pacific Halibut hook and line L licence fishery sets from 2007-2017 coastwide (all management areas). b) Annual Number of Skippers within the L Licence Pacific Halibut Hook and Line Fishery from 2007-2017 coastwide (all management areas). c) Annual Number of Vessels within the L Licence Pacific Halibut Fishery 2007-2017 coastwide (all management areas).
Figure 10: Total Allowable Catch of Halibut (tonnes) allocated to the B.C. Halibut hook and line commercial fishery (all management areas), between 2007 and 2017.

Fishing effort distribution maps show key locations of Halibut catch (Figure 4), and Yelloweye catch (Figure 5) in Area 5 and Area 3. Key locations within larger fishing grounds can be seen as smaller hotspots along the coast (redder colours), the majority of which lay within Area 5. The commercial Halibut fleet has decreased its overall setline density by 40% over all areas (coastwide) for both Halibut catch (Figure 4) and Yelloweye catch (Figure 5). A database query of fishing activity (measured by latitude and longitude of setline start and end points) by management areas revealed that recent fishing activity has mainly been concentrated in Area 5, with 84% of all Halibut longline sets from 2007 to 2017 occurring within Area 5 (Figure 4).

4.1.2 Yelloweye TAC

Yelloweye TAC allocated across all sectors (commercial, research, recreational and food and ceremonial) decreased from 284 tonnes in 2007-2015 to 179 tonnes in 2016 and was further reduced to 113.9 tonnes in 2017 (Figure 11). The Yelloweye TAC allocated to the L licence category was reduced from 92 tonnes in 2015 to 57 tonnes in 2016 (a 38% reduction) (Figure 11). In 2017 it was reduced to 35 tonnes, representing a further reduction of 39%, and a total reduction of 57 tonnes (or 62%) from 2015 (Figure 11).
Yelloweye was the only quota managed species within the B.C. Halibut hook and line fishery to experience such large reductions in TAC.

*Figure 11: Annual coast-wide Yelloweye TAC across all sectors (blue) and allocated to the L License category (orange) from 2007-2017.*

Such a large decrease in TAC supports the likelihood that Yelloweye is a choke species, according to the criteria for choke species set out in Section 2.6, i.e., there have been notable reductions in Yelloweye TAC (Criteria 1, 2 and 4) and there is apparent overlap in catch distribution of these species (Criteria 3; Figure 4, Figure 5).

The proportion of landed Yelloweye within areas 5A, 5B, 5C, 5D and 5E was notably lowest in Area 5D (Figure 12). In 2016/2017, the proportion of landed Yelloweye increased in Area 5E, 5D and 5c but decreased in areas 5B and 5A (Figure 12). All areas show a variation over time in proportion of landed Yelloweye.
Figure 12: Proportion of landed Yelloweye by Area 5 sub-areas in spring and summer months from 2007-2017.

Yelloweye TAC was notably reduced in the 2016-2017 fishing seasons. An examination of the OAHLBH depth stratified survey data verifies that Yelloweye are still present in B.C. waters (Figure 13). In Area 5A, the median number of Yelloweye per km² was highly variable, but Yelloweye was present in all years. The inter-quartile ranges in 2014 and 2016 are very similar, suggesting that the density of Yelloweye was similar in 2016 to 2014 (Figure 13). The median number of Yelloweye per km² was never above 50 in Area 5A (Figure 13). Area 5B had a much larger variation in distribution in number of Yelloweye per km² than Area 5A (Figure 13). Median ranges in Area 5B were mostly below 50 Yelloweye per km². Median values in Area 5B varied across years, with 2016 having the lowest median Yelloweye per km² (Figure 13). Area 5C was sampled in seven of the last 10 years and showed less variation in density of Yelloweye than other areas. Median density was lower (equal to or less than 25 Yelloweye per km²) than 5B but higher than Area 5A in most years (Figure 13). Area 5D had the lowest median density of Yelloweye (less than 25 Yelloweye per km²) but showed a slight increase from 2012 to 2015 (Figure 13). Area 5E had a median density of Yelloweye (over 100 Yelloweye per km²) in 2015, with a notable increase from 2012 (Figure 13). These survey data indicate that Yelloweye are still present in all management areas of Area 5. Therefore, they have the potential to cause fishers to avoid them in the presence of a low TAC.
Figure 13: Area 5 A, B, C, D and E OAHLBH survey data indicating the number of Yelloweye per km2 over OAHLBH survey years. Note different scales. Source: DFO, unpublished data.
4.1.3 Intra-annual seasonal patterns

The proportion of sets and proportion of landings across all years was compared between the fall & winter seasons (September-November) and the spring & summer seasons (March-August) (Figure 14). Marked differences in proportion of sets were found between different seasons (Figure 14), i.e., approximately 75% of sets and landings occurred in spring and summer. Therefore, for tractability, the remainder of this section focuses on spring and summer patterns.

![Figure 14: (a) Proportion of B.C. Halibut hook and line sets and (b) Proportion of Landings (all species) throughout the seasons Fall & Winter (September-November) and Spring & Summer (March-August) from 2007-2017.](image)

Distribution of annual commercial fishing effort (number of sets) by month was calculated from 2007-2017 and is presented using polar histograms (Figure 15). Trends are consistent with results from Section 4.1.1, which indicate that number of sets has decreased by 53% from 2007 to 2017 (Figure 9), following a reduction of 50% in the Halibut TAC since 2007 (Figure 10). Seasonal trends varied across the years, with some years having more spring fishing than others (e.g., 2015). However, for most years, a greater proportion of sets were made in the summer (54%), mostly in July and August, compared to the spring (21%) Figure 15). Information from the interviews of skippers indicates that an increase in
summer fishing may be because of better weather (spring weather is more variable), fish encountered are anecdotally larger and prices are usually higher for larger fish.

Figure 15: Polar histograms of annual number of sets by month throughout the B.C. Halibut hook and line fishing season from 2007-2017, and for all years (last figure) for all skippers. Dotted coloured lines indicate number of sets (see legend). Source: DFO, unpublished data.

Total annual landed Yelloweye (kg) was examined by season. For all years, notably less Yelloweye was caught in the spring than in the summer (Figure 16a). Total annual landed Yelloweye decreased in both spring and summer in post years (2016-2017) compared to prior years (2007-2015) (Figure 16b).
Moreover, the total proportion of landed Yelloweye (kg, as proportion of total spring and summer landings) decreased by more than 50% in spring from 2015-2017 (Figure 17a). The relative proportion of landed Yelloweye in summer increased over the last three years of the time series years, despite an overall decrease in landings (Figure 17a and Figure 16a respectively). This suggests that skippers could have been “saving” their Yelloweye quota for the summer months when the most Halibut fishing occurs. Indeed, the overall proportion of landed Yelloweye in the spring in prior years (0.26) decreased compared to post years (0.19), while the proportion landed in the summer increased from prior (0.76) to post years (0.87) (Figure 17b).
4.2 Depth Analysis

4.2.1 Fishery independent survey depth data

Depth encounters of Halibut and Yelloweye in the IPHC setline survey were found to overlap (Figure 18). The 95% percentile range of the depth distribution of Yelloweye ranged from 54 m (2.5%) and 242 m (97.5%). The depth distribution of Halibut ranged from 47 m (2.5%) and to 374 m (97.5%). Therefore the overlap of depth distributions of Yelloweye and Halibut was between 54 m and 242 m (Figure 18). These patterns were consistent among years (2007, 2015 and 2016 shown in Figure 18).
Figure 18: Annual histograms of the depth distribution of IPHC scientific survey sets which encountered Halibut (in blue) and Yelloweye (in orange) a) 2007 b) 2015 and c) 2016. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps. d) Figurative Venn diagram of overlapping Halibut and Yelloweye depth distributions from the annual IPHC fishery independent survey

4.2.2 Commercial depth data

Histograms of the depths where Halibut and Yelloweye were encountered in the commercial fleet show that Halibut and Yelloweye fishing grounds overlap (Figure 19). The 95% confidence interval of the depth distribution of Yelloweye for Area 5 was between 43 m (2.5%) and 290 m (97.5%) (Figure 19). The depth distribution of Halibut for Area 5 was between 46 m (2.5%) and 379 m (97.5%). Therefore the overlap of depth distributions of Yelloweye and Halibut was between 43 m and 290 m (Figure 19). Examining the intra-annual patterns it was evident that there were fewer sets in spring and Halibut sets were notably deeper than in summer (Figure 20). In summer there was a much
greater proportion of sets in shallower waters, and much greater overlap of Halibut and Yelloweye depth (Figure 20). All commercial results indicated a reduction in the number of sets over time (Figure 19, Figure 20).

Figure 19: Annual histograms of the depth distribution of commercial fishery sets, which encountered Halibut (in blue) and Yelloweye (in orange) a) 2007 b) 2015 and c) 2017. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps. d) Figurative Venn diagram of overlapping Halibut and Yelloweye depth distribution encounters from commercial data.
Figure 20: Annual histograms by season (spring and summer) of the depth distribution of commercial sets that encountered Halibut (in blue) and Yelloweye (orange): a) number of spring sets in 2007 by depth; b) number of summer sets in 2007 by depth; c) number of spring sets in 2015 by depth; d) number of summer sets in 2015 by depth; e) number of spring sets in 2017 by depth; and f) number of summer sets in 2017 by depth. Vertical lines denote the 2.5 and 97.5 percentiles of the depth distribution of each species and where their distribution overlaps.

Weekly plots of the depths of commercial setlines (all years from 2007-2017) in the commercial fishery data confirm that the fleet moves into shallower water throughout the spring into summer (Figure 21). These results are consistent with tagging results by Loher (2011), who showed that tagged Halibut move into deeper water in the winter.
months and come up onto the continental shelf (above 200 m) in the late spring (April) and remain in shallower water throughout the summer months (Figure 22; note that months are offset by six months compared to Figure 21). The mean depth of sets in March was 265 m. In the first week of April the mean depth of longline sets was 227 m and by the end of April the mean depth of sets was 165 m. In the first week of May the mean depth of longline sets was 125 m and from the first week of June the mean set depth remained relatively steady until the beginning of August with an overall mean set depth of 114 m (Figure 21). The standard deviation was larger in the spring months than in the summer, where most sets were around 100 m until the end of September, when the mean set depth increased to approximately 200 m, going as deep as 300 m near the end of October (Figure 21).

Figure 21: Weekly set depths of the B.C. Halibut hook and line fishery from 2007-2017. Blue boxes indicated interquartile range for each week, grey vertical lines indicated monthly divisions and black horizontal lines indicate the median depth of sets (note that months are offset by six months compared to Figure 22).
Figure 22: Mean maximum daily depths of 19 tagged Pacific Halibut displaying offshore-onshore seasonal migration from Kodiak Island Alaska to Cape Flattery Washington (reproduced from Loher, 2011 with permission from the author) (Note that months are offset by six months compared to Figure 21).

Across all Halibut sets, the mean annual set depth was deeper in the spring than in the summer for all study years (Figure 23a). However, the fleet has moved into deeper water in recent years in both spring and summer relative to other years, especially in the summer months (Figure 23a). For sets that did not catch any Yelloweye, mean depth in both spring and summer increased in 2017, although confidence intervals were broad (Figure 23b). In 2017 in spring, both the mean and median depth increased compared to 2016 (Figure 23b). Halibut sets that did catch Yelloweye did not indicate any depth trends in recent years, remaining stable at around 100 m (Figure 23c). In general, as expected from the depth histograms (Figure 17), Halibut sets that did not catch Yelloweye (Figure 23b) were deeper and covered a greater depth range than sets that did catch Yelloweye (Figure 21a and 23c). Plots by sub-area are shown in Figure 39 and 40 in Appendix C.
Figure 23: a) Depth (m) of all B.C. Halibut hook and line sets from 2007-2017 in the spring (left panel) and in the summer (right panel); b) depth (m) of all Halibut hook and line sets which did not encounter Yelloweye Rockfish from 2007-2017 in the spring (left panel) and in the summer (right panel); and c) depth (m) of all Halibut hook and line sets which did encounter Yelloweye Rockfish in the spring (left panel) and summer (right panel). Boxes denote interquartile range of set depth. Horizontal black lines indicate median depth while black dots indicate mean depth of sets.
4.3 Location of Fishing Grounds

4.3.1 Fishing locations prior and post- Yelloweye quota reduction

Fishing grounds were plotted by filtering all setline data for the Halibut hook and line fleet for prior and post years retaining only clusters with a minimum size of 10 km² with three or more vessels. This ensures maps are Privacy Act compliant for publication purposes but eliminates many small fishing grounds frequented by three or fewer vessels (Privacy Act, 1985). This analysis is intended to gain an illustrative ‘big picture’; Sections 4.4 and 4.5 provide a finer scale data analysis.

The size of the effective fishing grounds is notably smaller in post years (dark blue) in both spring and summer than it is in prior years (light blue) (Figure 24a and Figure 24b). There are more sets in prior years because of the longer time period that defines prior years (2007-2015) vs. post years (2016-2017) but it is notable that the fleet’s effective fishing grounds have lessened in both spring and summer. Prior and post years’ fishing grounds mostly overlap (e.g., Figure 24a circled cluster 1 and Figure 24b circled cluster 1.) with very few new fishing areas, with the exception of a few clusters in Area 5C in both spring and summer (e.g., Figure 24a circled cluster 2 Figure 24b circled cluster 2.). The summer post clusters in Area 5C (Figure 24b circled cluster 2) are not present in summer prior years but they are present in spring prior years (Figure 24a circled cluster 3) indicating a possible shift in fishing effort from spring to summer in this area (Figure 24). Spring fishing grounds are concentrated in a smaller area while summer fishing grounds cover more of the coastal waters for both prior and post years (Figure 24a and Figure 24b).
Figure 24: Effective fishing grounds in the B.C. Halibut fishery in a) spring months (March-April) and b) summer months (May-August) defined as groups of effective longline fishing sets that aggregate in the same geographic area. Data are presented in summary format in accordance to the Privacy Act (1985) for the time period and area of interest. Data not in accordance with this Act have not been included in these figures (Privacy Act, 1985).

4.4 TAC and Catch Ratios

The value of $R_T$ calculated from Equation 1 for Yelloweye TAC was -0.33, indicating a decrease post-2015, and indicating an increased incentive to avoid catching Yelloweye. The value of $R_C$ calculated from Equation 2 for Yelloweye was -0.32, closely matching the $R_T$. The TAC and Catch Ratio values are similar, indicating that fishers were able to adapt their fishing strategies to reduce their catches of Yelloweye in accordance with the reduction in TAC allocation.
4.5 Cluster Analysis

Cluster trees were formulated for each individual skipper from the sets of the top 80 skippers (example shown in Figure 8). In order to group individual sets into fishing opportunity clusters, a cut point was calculated as 0.235 km (Figure 8). Applying a cut point of 0.235 km to the cluster trees allowed the fishing grounds to be subdivided into multiple fishing opportunities.

The clustering resulted in several distinct fishing opportunities with setlines clustered close together while solitary sets (further away from the clusters) were considered exploratory and were not mapped (example shown in Figure 25). In this example, Fishing Opportunity 2 shows a small cluster of sets while Fishing Opportunity 8 shows a fishing opportunity with many setlines densely set over the same area (Figure 25). Applying smaller cut points to the cluster tree would result in more small fishing opportunities; while a larger cut point would result in fewer, larger clusters, eventually clustering all the sets into one fishing opportunity (see sensitivity analysis in Branch and Hilborn 2008).
Figure 25: Unique fishing opportunities for a randomly selected skipper. All identifying land features have been deleted to protect the skipper’s privacy.

The total number of annual sets made by the top 80 skippers ranged from 2,184 in 2011 to 3,255 in 2007 (Figure 26). After 2008 the number of sets decreased notably, which is consistent with the drop in Halibut TAC in 2008 (Figure 10). The average number of sets remained relatively stable around 2,378 from 2009-2017 (Figure 26).
Figure 26: Number of sets made by the top 80 skippers (by kg) within Area 5 in spring/summer seasons of the B.C. Halibut fleet from 2007-2017.

Figure 27: Number of fishing opportunities for the top 80 skippers (by kg) within Area 5 in spring/summer seasons of the B.C. Halibut fleet from 2007-2017.
The total number of fishing opportunities used by the top 80 skippers ranged from 247 in 2011 to 376 in 2015 (Figure 27). Number of fishing opportunities decreased after 2015 by 74 fishing opportunities, and then increased from 2016 to 2017 by 34 fishing opportunities (Figure 27). This does not correspond with the trends in number of sets during the same time period (Figure 26) and could be the result of exploratory fishing before the Yelloweye reductions (2015) and concentrated fishing effort opportunities post-2015 in areas where likely catch compositions were known. While the number of fishing opportunities increased in 2017, it did not increase back to 2014/2015 levels, when skippers may have been seeking new grounds. Examination of attributes of fishing opportunities showed clear seasonal patterns. Fishing opportunities tended to have most of their sets in either spring (example in Figure 28) or summer (example in Figure 29). Similarly, many skippers tended to favour fishing in spring or summer, with the majority of their sets made in one or the other season (Figure 29). The majority of skippers fished mainly in summer months with 61% of the top 80 skippers making the majority of their sets (≥60%) in the summer months compared to 21% of skippers who made the majority of their sets (≥60%) in the spring months. Multi-season fishing patterns were identified for a minority (18%) of the top 80 skippers who fished 41%-59% of their sets in both spring and summer from 2007-2017 (example in Figure 30).
Figure 28: Example of a selected spring-specialized skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017, separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities separated into spring and summer.
Figure 29: Example of a selected summer-specialized skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017 separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities, separated into spring and summer.
Figure 30: Example of a selected multi-season skipper indicating: a) annual number of sets across all fishing opportunities from 2007-2017 separated into spring (coral) and summer (teal); b) number of sets in each of their fishing opportunities; and c) the proportion of the skipper’s sets in each of their fishing opportunities, separated into spring and summer.

Obvious shifts in seasonal fishing behaviour from summer (when a greater proportion of Yelloweye are encountered) to spring (when a lesser proportion of Yelloweye are
encountered) were not evident in seasonal fishing opportunity plots in prior and post years. Select skippers did have a greater number of sets in “spring” fishing opportunities in post years than they did in “summer” fishing opportunities (Figure 31), but the reverse trend, where skippers had a greater number of sets in “summer” fishing opportunities in post years, was also apparent (Figure 31).

**Figure 31:** Number of sets in fishing opportunities in spring (coral) and summer (teal) from 2007-2017 for skipper: a) who has shifted sets from spring and summer in prior years (2007-2015) to exclusively spring after 2015 (post years); and skipper b) who has shifted from spring and summer sets in prior years to exclusively summer sets in post years.

### 4.5.1 Utilization Ratios

Fishing opportunities were categorized into the following four groups, according to their Utilization Ratio value:

- **Category 1:** $R_{U,i} = -1$ (abandoned),
- **Category 2:** $-1 < R_{U,i} \leq 0$ (negative),
- **Category 3:** $0 < R_{U,i} < 1$ (positive); and
- **Category 4:** $R_{U,i} = 1$ (new).

There was an absence of clusters in Category 4 because there were no completely new fishing opportunities identified in post vs. prior years. The largest proportion of fishing
opportunities fell into Category 1, abandoned fishing opportunities, with 62% of all fishing opportunities abandoned (Figure 32). Of these, a proportion of 0.585 were spring fishing opportunities and a proportion of 0.618 were summer fishing opportunities (Figure 32). The large proportion of abandoned fishing opportunities is consistent with previous findings, that the total number of sets has decreased across the whole fleet since 2007 (Figure 9), fishing set density has decreased (Figure 4, Figure 5), the area of fishing grounds has decreased (Figure 24) and, within the top 80 skippers, number of sets has decreased overall (Figure 26). Also, given that there are more years in the post vs. prior period, there is a greater likelihood that some of the fishing opportunities in the prior period would not be re-visited in the two-year post period (see below).

The next largest proportion of fishing opportunities fell into Category 3, positive utilization, with a proportion 0.275 of spring fishing opportunities and a proportion 0.251 of summer fishing opportunities (Figure 32). A positive utilization ratio indicates fishing opportunities that are being utilized more in post years compared to prior years. Finally, the fewest proportion of fishing opportunities fell into Category 2, negative utilization (Figure 32) with a proportion 0.14 of spring fishing opportunities and a proportion 0.131 of summer fishing opportunities. A negative utilization ratio indicates fishing opportunities that are being utilized less in post years compared to prior years but have not been abandoned completely.

As noted above, skippers abandoned a proportion 0.585 of their spring fishing opportunities compared with a proportion 0.618 of their summer fishing opportunities (Figure 32). Summer sets tend to occur in shallower water, and have high Halibut and Yelloweye overlap (Figures 19 and 20), while spring sets occur in deeper water (Figure 21). Conversely, skippers increased utilization of a proportion of 0.275 of their spring fishing opportunities compared with only a proportion of 0.251 of their summer fishing opportunities (Figure 32). While the differences are small, this result suggests a possible shift towards deeper spring fishing opportunities for some skippers, and away from shallower summer fishing opportunities.
Figure 32: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2007-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one.

Sensitivity of utilization patterns to choice of prior years was examined using three sets of redefined prior years (2009-2015, 2012-2015 and 2014-2015. For prior years 2009-2015 (Figure 33) trends were similar to the base case (prior years 2007-2015; Figure 32) with a proportion of 0.555 abandoned fishing opportunities (Category 1) occurring in spring and a proportion of 0.584 occurring in summer. There was less difference between negatively utilized fishing opportunities (Category 2) than in the base case, with a proportion of 0.171
in spring and a proportion of 0.173 in summer. This is compared to the base case, which had a proportion of 0.14 of spring fishing opportunities and a proportion of 0.131 of summer fishing opportunities in Category 2. Category 3 was very similar to the base case with a proportion of 0.274 of spring fishing opportunities and a proportion of 0.243 of summer fishing opportunities (Figure 33).

**Figure 33:** Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2009-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one.
Sensitivity to the base case (Figure 32) was also examined using redefined prior years of 2012-2015, chosen because Halibut TAC was very similar across these years (Figure 10). In this case, seasonal patterns were slightly stronger than in the base case, with a proportion of 0.447 of fishing opportunities in Category 1 in spring and a proportion of 0.501 occurring in summer. There was a slightly greater seasonal difference in Category 2 fishing opportunities than in the base case with a spring proportion of 0.249 fishing opportunities and a proportion of 0.227 in summer. In Category 3, there was a 0.304 proportion of spring fishing opportunities compared to 0.273 in summer. This represents a slightly stronger difference in spring vs summer fishing in positively utilized fishing opportunities.
Figure 34: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2012-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one.

Finally, sensitivity to the base case (Figure 32) was examined with an equal number of prior (2014-2015) and post years (2015-2017) (Figure 35). Trends were quite different to the base case, with a much more even distribution of utilization across the three categories and weak to no seasonal patterns. There was a proportion of 0.372 of fishing opportunities in Category 1 in spring and a proportion of 0.373 fishing opportunities occurring in
summer. Compared to the base case, Category 2 had a larger proportion of fishing opportunities in both spring and summer with a proportion of 0.33 of fishing opportunities in the spring and 0.326 in the summer (Figure 35). This was very different to Category 2 in the base case, which had a proportion of only 0.14 fishing opportunities in the spring and a proportion of 0.131 in the summer. Category 3 had a proportion of 0.299 of spring fishing opportunities and a proportion of 0.301 of summer fishing opportunities (Figure 35).

Figure 35: Proportion of fishing opportunities for top 80 skippers (by kg) in the B.C. Halibut hook and line commercial fishery by utilization ratio categories separated into spring (March-April) and summer (May-August) seasons from 2014-2017. Values are indicated for each season on the plot. Note: Proportions are calculated for spring and summer separately i.e. spring proportions add up to one and summer proportions add up to one.
Through visual examination of the catch composition as a function of depth and $R_{U,t}$ categories from all 80 skippers, I found three general trends apparent in 90% of these skippers:

1) Skippers who shifted into deeper waters (example in Figure 36a);
2) Potentially species-selective skippers (i.e. “shopping list” skippers who selectively target many species along with Halibut) who maintain Yelloweye catches and depth profiles (example in Figure 36b); and
3) Shallow water skippers who maintained their depth profile but abandoned fishing opportunities with higher proportion of Yelloweye (example in Figure 36c)

For the remaining 10% (8 skippers), I could not discern any trends, either because there were only a few fishing opportunities in prior and post years or they had very few fishing opportunities overall. Note that all skippers had a high proportion of abandoned clusters. This is most likely an artefact of the design of the Utilization Ratio (Equations 3 and 4), which compares average utilization in two post years (2016-2017) with average utilization over a period of nine prior years (2007-2015). Given that the prior years cover such a long period, it is quite likely to find fishing opportunities that were not re-visited in the two-year post period. A data query indicated the majority (73%) of the top 80 skippers had Category 1 (abandoned) sets that included Yelloweye. The remaining 27% of skippers either: 1) had no abandoned fishing opportunities; 2) had abandoned fishing opportunities within the 150 m depth range but that did not encounter Yelloweye; or 3) had abandoned fishing opportunities with Yelloweye encounters but were deeper than 150m (Figure 36).
Summarized attributes of fishing opportunities in terms of species composition are shown in Figure 34. Note that the mean proportion of each species (Yelloweye or Halibut) represents the mean proportion of the species among all sets within each fishing opportunity, across all years. Boxplots summarize these means for all fishing opportunities within the same category, with mean and median of the means represented as a black dot and coloured bar, respectively.

The mean of the mean proportion of Yelloweye landed in Category 1 (abandoned) fishing opportunities was the same in spring and summer (0.07) (Figure 37a). In Category 3 (positive) fishing opportunities, the mean proportion of Yelloweye was slightly greater in the summer (0.04) compared with the spring (0.03). There was a higher mean proportion of Yelloweye in Category 2 (negative) fishing opportunities compared to Category 3 (positive), which is interesting, as it may indicate a shift away from fishing opportunities with more Yelloweye, suggesting that skippers are successfully avoiding Yelloweye. There was a slightly larger mean proportion of Yelloweye in Category 2 (negative) fishing opportunities in spring (0.07), suggesting skippers in post years may be saving their Yelloweye to be caught in summer months (0.05), further evidenced by the slightly greater proportion of Yelloweye landed in Category 3 (positive) in the summer compared to the spring (Figure 37a). This supports an earlier finding that a greater proportion of the Yelloweye catch is taken in the summer in post years compared to prior years (Figure 17). There was a statistically greater proportion of Yelloweye caught in Category 1 and Category 2 than compared to Category 3 calculated by the nonparametric Kruskal-Wallis test ($H = 15.067$, d.f. = 2, $p < 0.001$) indicating avoidance behaviour.
The mean proportion of Halibut landed in fishing opportunities in Category 1 (abandoned) was higher in the summer (0.67) than in the spring (0.61) (Figure 37b). The fishing opportunities in Category 2 (negative) also had a notably lower mean proportion of Halibut caught in the spring (0.62) than in the summer (0.70) (Figure 37b). Fishing opportunities in Category 3 (positive) had a higher proportion of Halibut landed in the summer than those in Category 2 (Figure 37b). Not surprisingly, as skippers are targeting Halibut there was a statistically significant greater proportion of Halibut caught in Category 3 than in Category 2 in both seasons combined, calculated by the nonparametric Kruskal-Wallis test (H = 37.311, d.f.= 2, p < 0.001).

**Figure 37**: Base Case 2007-2017: Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: b) Mean proportion of Halibut (mean among sets within fishing opportunities) landed by the top 80 skippers (by landed kg) in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

Sensitivity to the choice of prior years was tested using a new definition of prior years (2009-2015) (Figure 38a). The mean of the mean proportion of Yelloweye landed in Category 1 (abandoned) fishing opportunities was the same in spring and summer (0.07)
(Figure 38a). In Category 3 (positive) fishing opportunities, the mean proportion of Yelloweye was the same in spring compared with summer (0.04). There was a slightly larger mean proportion of Yelloweye in Category 2 (negative) fishing opportunities in spring. There was a statistically greater proportion of Yelloweye caught in Category 1 (abandoned) and Category 2 (negative) than compared to Category 3 (\(H= 18.746, \text{d.f.}= 2, p= 8.497\times 10^{-5}\)), which was similar to the base case with prior years 2007-2015.

The mean proportion of Halibut landed in fishing opportunities in Category 1 (abandoned) was higher in the summer (0.67) than in the spring (0.61) (Figure 38b). This is compared to the base case, which had 0.61 in the spring and 0.67 in the summer. The fishing opportunities in Category 2 (negative) had a higher mean proportion of Halibut caught in the spring (0.65) than in the summer (0.71) (Figure 38b) compared to spring in the base case (0.62) and summer in the base case (0.70). Fishing opportunities in Category 3 (positive) had a higher proportion of Halibut landed in the summer (0.75) than those in Category 2 in summer (0.71) (Figure 38b) similar to the base case. There was a statistically greater proportion of Halibut caught in Category 3 than in Category 1 and Category 2 (\(H= 24.204, \text{d.f.}= 2, p= 5.548\times 10^{-6}\)). The main differences between this sensitivity analyses (with prior years defined as 2009-2017) is the seasonal trends between spring and summer were weaker but over all this sensitivity analysis followed similar patterns to the base case.
Figure 38: Sensitivity analysis prior years defined as 2009-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: b) Mean proportion of Halibut (mean among sets within fishing opportunities) landed by the top 80 skippers (by landed kg) in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

For sensitivity analysis, mean proportion of Yelloweye and Halibut across utilization ratio categories was also calculated using a new definition of prior years (2012-2015) (Figure 39). In Category 1 (Figure 39a) the mean proportion of Yelloweye caught in the spring was larger (0.08) than in the spring in the base case (0.07) (Figure 37a) where as the summer proportion was the same (0.07) compared to the base case (0.07) in Category 1. In Category 2 there was also a smaller mean proportion of Yelloweye caught in spring (0.05) and summer (0.04) compared to the base case in spring (0.07) and summer (0.05). In Category 3 there was a higher mean proportion of Yelloweye landed in spring (0.04) but not in the summer (0.04) compared to the base case spring (0.03) and summer (0.04). These seasonal differences are small but follow similar trends to the base case proportions. There was a statistically greater proportion of Yelloweye caught in Category 1 and Category 2 than compared to Category 3 calculated by the nonparametric Kruskal-Wallis test (H= 22.457, d.f.= 2, p= 1.329e05)
The Mean proportion of Halibut was also calculated for prior years 2012-2017 (Figure 39b) to compare to the base case (Figure 37b). Trends across Categories followed similar trends to the base case. Seasonal trends were also very similar (Figure 37b). There was a statistically greater proportion of Halibut caught in Category 3 than in Category 1 and Category 2 as calculated by the nonparametric Kruskal-Wallis test ($H = 14.126$, d.f.$= 2$, $p= 0.0008563$).

Finally, mean proportion of Yelloweye and Halibut across utilization ratio categories was also calculated using prior years 2014-2015 (Figure 40). Trends across Categories for the mean proportion of Yelloweye were very similar to the base case. In Category 2 there was lower proportions in both spring (0.06) and summer (0.04) compared to the base case spring (0.07) and summer (0.04). Category 3 also had slightly lower proportion of Yelloweye caught in the spring (0.02) but the same amount in summer (0.04) compared to the base case spring (0.03) and summer (0.04) (Figure 40a). The trends in the mean

Figure 39: Sensitivity analysis prior years defined as 2012-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: b) Mean proportion of Halibut (mean among sets within fishing opportunities) landed by the top 80 skippers (by landed kg) in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.
proportion of Halibut indicated weaker trends (Figure 40b) than compared to the base case (Figure 37b) There was a statistically greater proportion of Yelloweye caught in Category 1 and Category 2 than compared to Category 3 (H= 9.6547, d.f.= 2, p= 0.001415). There was a statistically greater proportion of Halibut caught in Category 3 than in Category 1 and Category 2 (H= 9.6547, d.f.= 2, p= 0.008008).

**Figure 40:** Sensitivity analysis prior years defined as 2014-2015. Boxplots of a) Mean proportion of Yelloweye (mean among sets within fishing opportunities) landed by the top 80 skippers in spring and summer over utilization ratio categories: b) Mean proportion of Halibut (mean among sets within fishing opportunities) landed by the top 80 skippers (by landed kg) in spring and summer over utilization ratio categories: Category 1: abandoned, Category 2: negatively utilized and Category 3 positively utilized. Mean across all fishing opportunities indicated by a black dot, values indicated in text above dot. Median indicated with coloured line. Note: the y-axis is truncated to improve readability.

### 4.6 Interview Analysis

All of the fishermen interviewed had more than 10 years’ experience fishing for Halibut. Three fishermen were interviewed in person, which allowed me to directly consult them with results from the cluster and utilization ratio analyses. Fishermen were asked about areas they fished in 2007-2015 and areas where they did not return to fish in 2016 and 2017 (R<sub>U,i</sub> Category 2). The three most common answers were: 1) There wasn’t enough Halibut to make it worthwhile to go back; 2) There was too much Yelloweye making it impossible to go back due to quota limits; 3) I didn’t need to go back because I caught my
Halibut elsewhere. One interview subject mentioned cost calculations as a potential reason they might not return to a fishing opportunity:

“If you are going to be out there for many extra days in order to fulfill fishing objectives, you might be encountering much higher costs, you know for food, for fuel, for grub, and that would offset any increase price you might get so, every fishermen does this calculus on every trip. You might have overall strategies but that would be very much influenced by the events of the day.”

Another skipper mentioned factors such as tides and weather as influencing factors when asked why they may not return to an area:

“Less halibut than what I think is acceptable for creating a timely fishing trip, which is going out, catching our fish, as much as we want that trip and coming back in. Some areas are just, you go there you fish, the tide sucks and it is just not a nice place to fish, like Triangle Island, Solander Island, those areas just suck for tide and wind. All sorts of reasons… I’m of a breed, you go somewhere you have success and you keep going back there”.

Three of the five-interview subjects were presented with their fishing history maps and asked questions about specific clusters. Experience was one factor that caused skippers to abandon fishing opportunities:

“Because there was very little halibut poor fishing area no previous knowledge, that is the same for all sets within that area, that was my first trip running the vessel without the retiring skipper on board, there was large tides so I was experimenting on the East side of Hecate”

While looking at a map of a cluster of sets on a popular fishing ground, one skipper mentioned it was the low abundance of Halibut that caused them to abandon a fishing opportunity. This low abundance was attributed to competition from other groundfish fisheries: “Those were most likely abandoned due to lower volumes of Halibut, that is a heavily fished trawl area”. This same skipper went on to mention there are still a few boats fishing there but “I believe I have found the area where I can get the highest return for the least amount of effort, so unless I, unless there is no fish there, then I would have no reason to fish anywhere else”.
One skipper who identified as a summer-specific fisher, attributed competition for the best fishing grounds to be a reason not to have returned to a productive fishing opportunity:

“It can be the best halibut spot on the coast and if a bunch of boats have been there just before you get there you are likely to have lessened fishing, on the other hand if you go to a spot that is maybe not quite as prime of spot, but nobody has been there for weeks you are liable to have good fishing”

Two skippers mentioned they did not return to a specific cluster because of an abundance of choke species:

“I haven't been there for many years although it is still a well-known halibut spot and I know people still go there, I don't go there out of fear of Yelloweye. I have looked back at my old log books, as I have been running past there wondering if I should stop and give it a try and then I look at how much Yelloweye I used to get there and I thought: no, I can't take the chance”

One skipper reported that in 2016 they were able to employ similar fishing techniques as before the Yelloweye reductions because they had enough carry-over from the previous season to cover their catch, but in the 2017 fishing season they had to change areas, abandoning good Halibut areas to avoid encountering too much Yelloweye.

Interviewees indicated that a small proportion of the fleet may still target Yelloweye and other non-Halibut species as a way to supplement their earnings (see example of multi-species skipper in Figure 36). This fishing strategy may include targeting of Sablefish (commonly called Black Cod), Lingcod, Yelloweye and Quillback Rockfish, which are some of the most common species sought. Because of reductions in Yelloweye TAC, interviewed skippers expected this behaviour to be reduced for species that share habitat with Yelloweye (e.g., other shallow water rockfish).

“There are vessels who fish where they can fill out their shopping list as it were, or address their entire portfolio of fish, so they might be fishing halibut in deep water so that they can catch Black Cod along with it. If they have Black Cod quota and if they have a Black Cod licence even more so, so they would be doing combination fishing. There might be other vessels that have a good Lingcod quota and want to
catch their halibut in combination with Lingcod and they would be going to other places where they know there is Lingcod.”

Two skippers mentioned they targeted Yelloweye but not until the last sets of their last trip as they wanted to make sure they had enough Yelloweye quota to cover their Halibut fishing and found it more profitable to target Yelloweye than to lease that quota.

One skipper said it was the fish buyer who dictated what species they should target:

“If the buyer is looking to fill a market request for Yelloweye he will typically contact us and ask us to go fish some Yelloweye or some Black Cod to make our trip worthwhile and that is typically because I believe he has a market for that fish and the market has not been filled by the previous landings.”

This skipper also mentioned that they would change their depth range in order to target specific species such as Lingcod, Sablefish and Yelloweye. They mentioned that the buyer might have multiple boats fishing in similar time frames and would ideally like them to stagger their landings and to bring in a variety of species instead of all the same species.

All fishermen who completed the survey identified themselves as either spring (see Figure 28) or summer fishers (see Figure 29) or a combination of both (none fished in the fall; Figure 30). When asked what characterizes spring fishing, all interviewees answered: 1) deeper than 235 m (130 fathoms; see Figure 20); 2) fewer non-target species encounters (such as rockfish and flounders); and 3) smaller Halibut (81-100 cm or 6.5-11.7 kg). Other responses about spring fishing characteristics included: worse weather in the spring; gear loss due to bad weather; having to fish further offshore; fewer boats present on the fishing grounds; and that Halibut are concentrated in smaller areas than in the summer (see Figure 24). In these smaller areas, the smaller Halibut seem to “fill in” quickly after a set, and multiple boats can fish the same area in a short period of time. Alternatively, in the summer, fishing opportunities are more spread out but can be “fished out” by a single boat, and require a week or so to be repopulated by larger Halibut (see Figure 24). When asked why they chose to fish in the spring one skipper answered, “because that is when we have always fished”. For this skipper, their successful fishing strategy and expert knowledge was spring-specialized, as summer fishing required a different knowledge base.
Fishermen characterized summer fishing as: 1) Shallower than 235 m (130 fathoms; see Figure 20); 2) closer to shore; and 3) larger Halibut (99-104cm or 11-13kg). All skippers except for one indicated that summer fishing was also characterized by higher incidence of rockfish encounters. The skipper who did not report encountering more rockfish in the summer indicated they set gear in deep water outside of the Yelloweye depth range (see Figure 18, Figure 19, Figure 20). Another skipper said they now choose more summer fishing because it was easier and safer than spring fishing (among other factors) and attributed this shift in priorities due to their increasing age and desire for a more comfortable fishing season:

“I have started to fish in more late spring and summer time in order to fish in better weather, I don’t want to fish big storms any more since I am an older fisherman now, so I like to fish in the summer months when the winds are less and the waves are smaller and I can anchor at night in a harbour rather than drift or jog all night”

When asked if they had changed their fishing strategies since the Yelloweye quota reduction, two interviewees said they had to avoid areas of high Yelloweye concentrations, and one said they had changed their actual fishing gear to try to avoid catches of Yelloweye. One skipper reported that the price of Halibut dictates when they fish, as smaller fish (encountered in the spring) are worth less per pound and bigger fish (encountered in the summer) are worth more. Fishing bigger fish in the summer can make a big financial difference to skippers who lease their quota from other people, as leasing costs can be high. Another skipper disagreed with seasonal size differences and attributed larger size of Halibut to where skippers decide to fish. Three skippers mentioned concerns about not being able to continue to fish in the summer as during these months Yelloweye are encountered incidentally (see seasonal depth distribution Figure 20), not as the result of targeting. One summer-specialized skipper was asked if their Yelloweye catch was incidental:

“Yes, if I knew more, or if I was a better fishermen I might be able to target more but I just target Halibut. I do not target Yelloweye; I try to avoid them if I can”

One of the skippers indicated they had so far been able to lease enough Yelloweye quota to employ similar strategies (i.e., fish in the same fishing opportunities in summer months) as
in previous years, but that encounters with Yelloweye are making it more difficult to access their Halibut catch:

“I have been able to access enough of these choke species by trading by using my network of friends and acquaintances, by using the fishing company that I am associated with and I have been able to come up with enough of these choke species to do this summertime fishery but it is getting harder and harder, there is another 30% reduction coming next season and it is going to be harder and harder to find enough Yelloweye and eventually I may be forced to change my plans”.

When asked about what they think has influenced where the Halibut fleet fishes, all subjects responded with concerns about low quota allocations of Yelloweye in contrast to the abundance at which they are found on the fishing grounds. They anecdotally report encountering Yelloweye in depths and areas they had not previously not encountered them before.

One skipper reported considering switching gear (to larger hooks) to potentially decrease their catch of Yelloweye but did not after hearing from another skipper who had tried this strategy that results were inconclusive. This skipper also mentioned potentially having to shift from their traditional summer fishing season (where they target larger Halibut in shallow water but encounter a large proportion of Yelloweye; Figure 20) to spring fishing, something they did not want to do because of crew schedule conflicts and bad weather. Having to shift to spring fishing was seen as a drastic tactic as it involved discarding all of their acquired summer fishing experiential knowledge and having to learn different spring fishing areas and strategies. Spring fishing, according to another skipper, requires at times the foregoing of sleep for multiple days in a row in order to take advantage of weather windows, high market prices or to keep fishing in an optimal fishing opportunity (as a result of competition from other fishers). All of the skippers interviewed mentioned moving into deeper waters to avoid encounters with Yelloweye. One of the skippers reported engaging in quota trading between areas, where they lease their valuable Sablefish quota and in return receive Yelloweye quota so they can continue to fish in the same fishing opportunities in the same season. One skipper reported type of bait is thought to influence what species are caught and time of day sets are left to soak. Each interview subject expressed that dealing with choke species causes tension. When asked how they
had changed their fishing strategies to avoid Yelloweye since 2015 one skipper answered they limit their exploratory fishing and stick to known fishing grounds: “We stay in deep water, or fish in spots know to be clean of Yelloweye. We fish with our guts churning, worrying about getting a bunch of Yelloweye”.

Four skippers, when asked about what is influencing where the Halibut fleet fishes, all reported Yelloweye as the primary reason fishers are changing their fishing behaviours. One skipper made the point that the whole fleet can potentially change their fishing behaviours to avoid Yelloweye, but this would mean the abandonment of the majority of fishing opportunities on the coast and the consolidation of the fleet into very few fishing opportunities in specific depths (greater than 300m), specific areas (select fishing grounds), and specific seasons (spring; see Figure 24). This skipper made the point that this could put a lot of pressure on these areas, and that competition among fishers to access these grounds could increase dramatically:

“The problem is if you change all your fisheries or you times of fisheries because you can’t go because there is an unrealistic number of Yelloweye quota available to fishermen, you are going to have everyone fishing in the spring, deep fishing in just a few certain areas so you are going to put undue pressure on certain areas at certain times, so it is not a feasible way to do it. A couple fishermen can change fishing patterns but if everyone does it then it will **** the system”

A spring-specialized skipper mentioned that a further Yelloweye reduction would not affect their fishing strategies but it would limit their options in the future:

“My fishing strategy at the moment is based on habit and the ability to catch fish in the spring, although I am not planning on changing my habit, the reduction on Yelloweye quota, it will largely affect my ability to choose the season in which I choose to fish. It limits my options to change the season in which I conduct my fishery. It will also affect a large portion of the fleet because if you had all of the fishermen fishing during the summer months, shift to fishing in the spring months to avoid catching Yelloweye, then you would find yourself with increased competition and less access to fishing grounds.”
They also highlighted that currently, because of the ITQ system and long season, there is very little competition for fishing grounds as there are many fishing opportunities spread over a large amount of time but that this may change if a large number of summer-specialized skippers begin fishing in spring months. This would potentially increase competition for the best sets as the effective fishing grounds in the spring are much smaller than in the summer (see Figure 24).

All skippers answered “yes” to the question “do you find it necessary to lease more bycatch quota to fish your Halibut?” Every one of them reported having to lease quota for bycatch species to access their Halibut quota, and three out of five skippers reported having to lease Yelloweye quota. When asked what they thought might have influenced where the Halibut fleet has been fishing since 2006 one skipper answered:

“Well for sure one of the main things [is] in recent years anyway is the encounters of choke species of rockfish, Yelloweye in particular whose quota has gone down disproportionally to the abundance of fish out there we are still encountering lots of Yelloweye, it is harder to avoid them, we are having to move from some places that are very productive halibut grounds because of encounters from Yelloweye”.

As a result of the interviews, I was able to add the names of common Halibut fishing grounds (circled in red, Figure 41) to an existing DFO chart that had common names of Pacific Cod (*Gadus macrocephalus*) fishing grounds (Figure 41). Having a chart with common names of fishing grounds helps combine quantitative and qualitative analysis and will help facilitate future dialogue between stakeholders on this subject. It may be useful in the reporting of areas where skippers encounter high rates of Yelloweye as areas to avoid in light of future Yelloweye reductions and further choke species avoidance behaviour. It should be noted that this is not an exhaustive list of fishing grounds and some common names may be not be the same as what all skippers use. According to the interview subjects, sets have been concentrated in smaller areas such as “the City”, “the Spit”, “Carpenter Bay spot” and off “Fredrick Hump” (Figure 41), which have remained areas of high setline density (Figure 5, Figure 6 and Figure 24). Interviewed skippers identified these grounds as having high Halibut density and relatively little Yelloweye bycatch.
Figure 41: Chart of common B.C. Halibut fishing grounds with some of the associated common names. Halibut grounds circled in red. Data gathered from interviews with skippers in the hook and line fishery. Note: this chart of common fishing ground names is not exhaustive or exact and common names might be known differently by individual fishermen.
4.6.1 Influences on Fishing Behaviours

Fishers choose where they fish for a multitude of reasons that are not always apparent in the data. Each fisher has a unique history and, even when fishers appear to make similar choices, the motivating factors that lead to those decisions may vary significantly. Motivating factors that affect fishers’ behaviour on the fishing grounds can be internal, external, individual or collective, all of which shape the decisions that fishers make at sea (Figure 42). This complex web of motivations, which affect physical behaviour on the fishing grounds, was interpreted through Ken Wilber’s Four Quadrant Integral theory model originally designed to integrate science and religion. I have adopted this model to represent the complexities present in the Halibut hook and line fishing fleet, based on the interviews I conducted with the five skippers (Wilber, 1998).
Figure 42: The Four Quadrant Integral Theory model (Wilber, 1998) applied to some of the many fishing effort decision drivers which influence spatio-temporal fishing behaviour. These factors were compiled from interviews with five active skippers.

**Internal/Individual**

These behaviour-influencing factors are rooted in individual or internal knowledge that can be at the level of an individual skipper or an individual boat. These factors can be thoughts, feelings, knowledge or perceptions.

1. Quota Ownership

   The amount of quota each skipper owns varies for each species. Some skippers have other groundfish licences that they hold quota on such as Rockfish or Sablefish, and they can fish those species while they are fishing for Halibut.

   Skippers who own their quota have more power to choose where they fish and how they will fish. Skippers who lease quota can be influenced by the owner of the lease (such as what price they want for it and if the skipper thinks it is worth it to capture those fish or just not to lease the quota) and how much quota they can find to lease.
Some skippers may trade species across different management areas and this may dictate where they can fish:

“I trade Yelloweye quota with people who fish in other areas like 5E on the west side of Haida Gwaii I trade with a guy there, I give him my 5E and he gives me his 5A and 5B so we do that kind of trading.”

2. Knowledge of weather (seasonal)
Most of the skippers mentioned weather being a factor when deciding where to fish. The weather in Area 5 is known to be more extreme in the spring. Bad weather can lead to loss of gear and loss of active fishing days, which both result in lost revenue due to costs of fuel, crew food and replacing gear. Weather can be much more reliable in the summer which makes fishing much more pleasant. As one skipper put it:

“I have started to fish in more late spring and summer time in order to fish in better weather, I don’t want to fish big storms any more since I am an older fisherman now, so I like to fish in the summer months when the winds are less and the waves are smaller and I can anchor at night in a harbour rather than drift or jog all night”

3. Dock Sales
Fishers are permitted to do dock sales directly to consumers if they obtain a licence. In order to sell to consumers, fishers are not allowed to process the fish in any way. This means selling the whole fish to consumers. Understandably, consumers are more willing to buy smaller fish (below 30 lbs) because, at $9/lb (in 2017), investment whole fish can be very expensive, not to mention freezer space can be quite limited. Targeting smaller fish to sell during dock sales can influence the spatial behaviour of fishermen.

4. Knowledge of Area/Seasons
A fishers’ intimate knowledge of local environmental factors can be quite detailed. For instance tides, local weather patterns, bottom type, currents and species composition are all factors fishers learn about after years of experience setting gear in the same place, or gaining that knowledge from other experienced fishers.
Fishers can attempt to target specific species or preferred sizes of fish, which affects their spatial fishing behaviour.

5. Experience: Tradition/habit
   One skipper mentioned that traditions heavily influence where they choose to fish. Their boat has a static crew and has always gone fishing during the same time of year, even after a change in skippers. To change this would be to break tradition and they are not willing to do that even if there might be benefits to shifting when/where they fish. Another skipper mentioned it was their experiential knowledge that dictated when they fished (and there for where).

External/Individual

These behaviour-influencing factors are unique to individuals but are tangible and measurable.

6. Participation in other fisheries
   Four out of five skippers all stated that part of what influences their fishing behaviour is the involvement in other fisheries that occur in set periods of time (dependent on openings, spawning times, and planned fishing trips or other factors). Because the Halibut fishery is largely conducted all year, only closing from November until March, they have more time to catch their Halibut quota, whereas some other fisheries can only be accessed during certain times. One skipper mentioned international market as an influencing factor:
   
   “We would fish in July exclusively because the Americans are busy salmon fishing so the American halibut fleet isn’t landing as much fish. The market is always better in July.”

7. Bait choice
   Each fisher has a preference for a type of bait to use. Salmon and squid are common but octopus is generally considered the best bait for catching Halibut, although it is also the most expensive. Octopus was reported by one skipper to not attract Yelloweye.
8. Buyer Pressure (which species to target)

One skipper said that one of the most influential factors that dictates where they fish is what species the fish buyer asks them to bring in. This can mean fishing in shallower or deeper water to target bycatch species, or travelling to a different fishing area entirely as some bycatch quota is area-specific. Another skipper said that the buyer takes care of the leasing of bycatch quota so they can cover what they catch while targeting Halibut.

9. Vessel and Fishing Gear Specifications

Three out of five skippers said that the size of their boat is a factor in where they decide to fish, one reported “I’m a little bit limited by my boat and gear; I definitely would not go fishing in March because of my boat”. The waters off the coast of Vancouver Island and Haida Gwaii can be subject to large swells from across the Pacific and storms can be dangerous in a small boat if there is no shelter available, this might mean some areas during parts of the year are not accessible. One skipper has adopted an integrated fishing strategy whereby they can fish in shallower waters where more bycatch species are present. This is to access larger Halibut because they have enough space in their hold for multispecies trips. Fishing gear is also crafted to fit the boat and the fishing strategy, deeper fishing in the spring means that more ground line (the line on which the hooks, anchors, buoys and flagpole are attached) is required, while summer fishing in shallower water requires less.

**External/ Collective**

These behaviour-influencing factors are what all fishers experience similarly but are from external sources.

10. Weather

Weather can be seasonal but it can also be unpredictable. Even if a fisher chooses to fish in the summer to avoid bad weather, storms still happen, and spring fishing can be mild during certain years. Weather variability and intensity as a result of climate change is something that may affect all fishers and might influence when they choose or are able to go fishing.
11. Quota Allocation: Target species/ Choke species

How quota is allocated for species across the fleet is one of the biggest influencing factors effecting when and where fishers choose to fish. An increase in Halibut quota will result in an increase in fishing effort, likely an increase in sets and therefore more fishing grounds are accessed. Less allocated Halibut quota may decrease the number of sets and the area fished. These of course are dependent on the abundance of Halibut. A bycatch species with low quota that is encountered frequently on the fishing grounds can create a choke species, which limits the harvesting of the target species. This can influence where fishers choose to fish so they can avoid low quota species and target species with higher quota species.

12. Market Factors/ Prices

This was brought up by one skipper who mentioned that market factors for the fish product can influence where fishers choose to fish. Large Halibut are anecdotally known to be encountered in shallow waters in the summer while smaller Halibut are anecdotally know to be encountered in deeper waters in the spring. If the consumer market demands either larger or smaller fish, then the fisher will go to wherever they can increase their profit. This also applies to choice of target species, i.e., if a bycatch species is highly valued then the fisher may shift their fishing strategy to catch more of the higher value product.

“Sure people are always looking at the bottom line and the bottom line includes the differential between the dock price and the lease price, if they are leasing any amount of fish. The calculation also includes the fuel price and how far you are going to have to go to get your fish, the bait price, how much bait you are going to use even down to the price of food… every fishermen does this calculus on every trip. You might have overall strategies but that would be very much influenced by the events of the day.”

13. National/ International Politics

Designation of Marine Protected Areas (MPAs) influences where fishers can set their gear. Canada agreed under the United Nations Convention on Biological Diversity to protect ten percent of coastal and marine areas by 2020 (Secretariat of the Convention on Biological Diversity & UNEP World Conservation Monitoring...
Centre, 2006). Canada met its goal of protecting five percent of coastal and marine areas by 2017 (DFO, 2018). This has an influence on where fishers can fish. Areas may be closed to commercial fishing, forcing fishers to make their sets elsewhere.

14. Orca/Whale Depredation

Three skippers mentioned avoidance of whales (specifically Orca and Sperm whales) that can eat large quantities of fish from the gear, as a motivating factor to shift their fishing behaviours. Alternate fishing behaviours reported include: moving to a different area to avoid whales; not fishing in certain areas known to be frequented by whales; or leaving the fishing grounds entirely and returning to port to allow whales time to move on to other food sources. This is a growing concern among fishers who report avoiding these types of interactions with whales at all costs.

15. Tides

Every fisher’s behaviour is influenced by the tidal cycles, as deploying or hauling back fishing gear can be complicated or hindered by the wrong tide. Alternatively, larger or smaller tides can be beneficial to a fisher’s fishing strategy, depending on what species they are targeting. Fishers report duration and strength of tides seem to affect catch rates of select species. One skipper reported moon phases influencing catch composition of sets.

**Internal/ Collective**

These behaviour-influencing factors are those that affect the fishing fleet as a group.

16. Quota Leasing: Availability/ Prices

One skipper reported trading the leasing of high value species quota for more Yelloweye quota so they can keep utilizing their fishing opportunities. The amount of quota of any type of species that is available can influence where a skipper can fish.

17. Market: Supply and Demand
Depending on the number of vessels fishing at one time, the buyer might try to stagger the landing of fish to take advantage of the markets. One skipper reported fish buyers telling them when to go fishing to ensure there is a steady supply of fresh Halibut. The type of bycatch species can also be specified for skippers to target depending on the market availability. A fish buyer can tell a skipper to target a specific species in order to fill demand. Fishers also try to stagger their catch among themselves so they do not flood the market. Another skipper stated “you always want to land your fish during high demand and low supply”.

18. Competition: Fishing grounds, Seasons

The Halibut hook and line fleet compete with other fishing gear types for fishing grounds. The groundfish trawl sector and the Sablefish sector use similar fishing grounds and each boat has to modify their fishing practices to account for other skippers utilizing other gear types.

Seasonal competition affects where skippers can fish. Usually the first few boats to land their catch at the beginning of the season (in March) get the highest price (because there hasn’t been any fresh fish since November in the previous year). There can be competition for the best fishing grounds as the most productive fishing grounds are relatively condensed and contested. Summer fishing is much more spread out, but there can also be competition for the best spots.
5 Discussion and Conclusion

In this section I discuss my initial hypothesis and answer research questions and sub-research questions outlined in Section 1. I also identify any unexpected findings and discuss them in context with previous work. Potential limitations of this study will be examined in light of how they might affect my results. A summary of the principal implications of my findings is discussed with connections to the literature. I discuss future recommended studies and management recommendations and finally, I present the conclusions of this thesis.

5.1 Discussion

5.1.1 Is Yelloweye a choke species within the integrated Pacific Canadian hook and line commercial Halibut fleet?

The first major finding of this study supports the hypothesis that Yelloweye qualify as a choke species within the multi-species B.C. commercial Halibut fleet (L licence), which has caused shifts in fishers’ spatio-temporal fishing behaviour. Within the Halibut fishery, Yelloweye meet the criteria for a choke species that were set out in Section 2.6. The species is caught in an ITQ fishery (Criteria 1). The fishery has a 100% discard ban for Yelloweye, which is enforced by 100% at-sea monitoring and 100% dockside monitoring program (Criteria 2). There is spatial overlap in depth for the target species Halibut and Yelloweye, evident in both survey and commercial fishery data (Criteria 3). Finally, using mixed research methods outlined in Section 2.9, a small pool of interviewed skippers attested to limitations of their ability to harvest Halibut and other species as a result of notable reductions in Yelloweye TAC (Criteria 4). Furthermore, several of the attestations by interviewed fishers that relate to their capability to avoid Yelloweye Rockfish were evident from analysis of the logbook data.

The emergences of choke species in fisheries around the world is a consequence of output controls in multi-species fisheries management such as TAC restrictions, ITQ systems and discard bans, which all seek to limit catches to conserve fish stocks. The emergence of choke species can be a result of successful conservation efforts, in which previously
depleted stocks recover and can then be encountered in abundance on the fishing ground, in contrast to the conservation-driven low quota allocation. An example of this is the European Hake (*Merluccius merluccius*) in the North Sea, where the species recovered much more quickly than expected, resulting in very low quotas for a newly abundant species (Baudron & Fernandes, 2015). Choke species scenarios can also be the result of a multi-species fishery where low productivity species share habitat with high value species restricting skippers’ fishing opportunities (Hatcher, 2013; Reeves & Davie, 2017; Schroepe, 2010). Schroepe (2010) emphasizes that choke species may arise as a result of a catch-share program which provides strong incentives for fishers to reduce their bycatch through policies which shut down fisheries once they have reached their allotted bycatch allocations. Hatcher (2013) considered the economic implications of continuing illegal discarding in a fishery with a discard ban as well as the costs of avoidance fishing in the presence of a choke species. Reeves and Davie (2017) found, in a paper evaluating choke species under the landing obligation in the Scottish fishing industry, that choke species problems are likely to arise in a fishery where the stock is weak “and/or there have been substantial changes in the stock or fishery since the quota share were established” (p. 17).

One choke species mitigation measure presented by Reeves and Davie (2017) is to allow an open quota trading system to allow fishers “flexibility to match their quota holdings to what they are actually catching” (p. 16). This system exists in the B.C. groundfish fishery. Alternatively, choke species can also result from policy and quota agreements, such as between Norway and Denmark, where Danish fishing effort in Norwegian waters is constrained by their ownership of Saithe (*Pollachius virens*) quota to cover catches (Mortensen et al., 2018). While it is not yet clear, Yelloweye may represent a combination of some of the above choke species scenarios. The 2015 Yelloweye TAC reduction was a result of estimates of low biomass resulting from a stock assessment, which recognized Yelloweye as a very long-lived species with low productivity (COSEWIC, 2008; Department of Fisheries and Oceans, 2015; DFO, 2015b). In light of this, it was important in this thesis to address the possibility that the observed reduction in catches of Yelloweye may not have been a result of successful fleet avoidance behaviours but rather a result of the elimination of Yelloweye presence on the fishing grounds. However, scientific survey data from a longline survey, optimised to catch rockfish, confirmed continuing presence of
Yelloweye on fishing grounds. Yelloweye status is to be re-examined by the COSEWIC committee in 2018 to determine the stock abundance (COSEWIC, 2008; DFO, 2015b).

Incidences of choke species “may result in less predictable limitations of effort” (Sigurðardóttir et al., 2015, p. 370) as fishers’ adaptive behaviours (avoidance behaviours such as spatial reallocation of effort) can have unforeseen consequences for fisheries management (Poos et al., 2010; Salas & Gaertner, 2004; Torres-Irineo et al., 2017). A report by PECH investigating Plaice (*Pleuronectes platessa*) as a choke species within the Baltic Sea, identified a number of potential solutions to the problem, summarized here into five key findings: 1) creating management incentives for fishers to avoid unwanted bycatch 2) facilitating a quota swap program 3) use of selective gear 4) spatio-temporal avoidance techniques based on fishers’ expert knowledge and 5) provisions for increased flexibility and exemptions of a landing obligation (Zimmermann et al., 2015). These measures are, for the most part, already in place in the B.C. Halibut fishery with an incentive based management ITQ system that allows quota to be traded, sold or leased amongst stakeholders with monitored and enforced discard restrictions. Subsequent findings of this thesis, document the potential establishment of novel fishing behaviour adaptations of the B.C. Halibut fleet in response to Yelloweye TAC restrictions.

5.1.2 What are the inter-annual and intra-annual patterns within the Halibut fleet?

The second major finding of this study answers Sub-Research Question 2. The B.C. Halibut fishery is characterized by patterns consistent with intra-annual Halibut migrations (Loher, 2011) which separate the fishery into two distinct seasons when the majority of the fishing effort takes place; spring and summer. Fishing season opening and closing dates are usually the result of economic and logistical factors (such as tides), and are recommended by stakeholders at the IPHC Annual Meeting (Loher, 2011). Seasonal patterns in fishing were strongly evident in the logbook data. While the commercial Halibut season lasts usually from March to November of each year, the migration patterns of Halibut affect how fishers target them in different months. Weekly trends in commercial set depths were consistent with results from previous tagging studies that tracked monthly depth patterns observed in tagged Halibut, i.e., Halibut are found in deeper water in winter/spring and move up onto the shallower continental shelf in summer (Clark & Hare, 2002; IPHC
Secretariat, 1987; Loher, 2008, 2011; Loher & Blood, 2009; St. Pierre, 1984; Webster et al., 2013). Examination of weekly commercial set depths showed that there are clear differences between spring/fall and summer fishing effort. This finding supported prevalent, but previously unpublished, common knowledge within the commercial Halibut fleet that spring fishing is characterized by deeper water fishing grounds while summer fishing is characterized by shallower water fishing grounds. There is evidence in the logbook data to suggest that some of the fleet has moved into deeper water since the reduction in Yelloweye TAC in 2016.

Inter-annual trends document a decline in Halibut quota allocation, number of vessels, number of skippers and number of sets (across the whole fleet) from 2007-2017. These trends show a steep decline in the initial years (2007, 2008), potentially as a result of management changes (integration of the groundfish fleet and ITQ allocation) and stock assessment changes (Halibut TAC reduction). From 2009-2017 these trends have stabilized. The number of sets, number of vessels and Halibut TAC have all increased slightly since 2015.

5.1.3 **What is the depth range of Halibut and Yelloweye in fisheries independent surveys and commercial fishing sets?**

Sub-Research Questions 3-7 were concerned with the depth ranges of the target species, Halibut and the choke species, Yelloweye. While Halibut are a migratory species and can be found in different depths depending on the season (Loher, 2008; Loher & Blood, 2009; Webster et al., 2013), Yelloweye are site specific (Hannah & Rankin, 2011; Love et al., 2002; Richards, 1986). Depth distributions in the fishery-independent IPHC survey showed that both Yelloweye and Halibut depth distributions overlap between the depths of 52 m to 242 m. Similarly, commercial logbook data showed that this overlap occurred between 43 m and 290 m. Fisheries independent survey data were used in this study to establish habitat overlap, although Jannot and Holland (2013) demonstrated in their study fishery that independent survey data can also be compared to commercial data to identify ecological vs. fishing effort drivers of bycatch encounters (Jannot & Holland, 2013). Pursuing a similar line of study to identify drivers of bycatch encounters is recommended as a future study for the B.C. Halibut fishery, as it can provide valuable information that can be used by managers to design bycatch mitigation measures (Jannot & Holland, 2013). So far, the
Halibut fleet has successfully avoided Yelloweye encounters to stay within the TAC allocation, this may be in part due to the flexibility the ITQ system has allowed skippers whereby they can trade and lease quota from one area to cover overages in other areas. So far this (among other factors) has helped mitigate much of the expected dramatic spatio-temporal shifts but there may be a limit as to how much quota can be shuffled through the fleet to cover Yelloweye encounters, especially if conservation efforts are helping the stocks rebound. Studies such as this, which establish seasonal fishing technique differences, are important for managers to better understand the intricacies of the fishery so that regulations can be effective to both maximize economic gains and meet conservation goals.

To qualify Yelloweye as a choke species, it was important to establish an overlap between Halibut and Yelloweye depth ranges. It is important to note though that differences in set depths between spring and summer skippers largely divides the fishery into two separate groups; those skippers who fish within Yelloweye depth range (summer fishers), and those who fish deeper than the established Yelloweye depth range (spring fishers). Catch records indicated Yelloweye was being caught in spring months by a number of skippers in large proportions, outside the seasonal Halibut depth range in spring. Examining the depth of sets that encountered Yelloweye in the spring suggested that these sets were targeted. A qualitative analysis of skippers’ behaviour was needed to investigate potential Yelloweye targeting behaviour. This will be discussed further in section 5.1.6.

5.1.4 Is there evidence commercial Halibut fishers have an incentive to avoid Yelloweye?

The third major finding of this thesis is that the Halibut fleet appears to be demonstrating successful avoidance fishing behavior to reduce their catches of Yelloweye. Having established that the fleet encounters Yelloweye over a large portion of the depth profile of the fishery, Research Question 8 follows: do Halibut fishers have an incentive to avoid the choke species Yelloweye? Bounded ratios, where the calculated ratio lies between 1 and -1, were used to measure this according to methods developed by Branch and Hilborn (2008). The Yelloweye TAC ratio (which measures the mean change in Yelloweye TAC prior to and post the 2016 TAC reduction) was calculated to be -0.33, a negative ratio, indicating the skippers had an incentive to avoid Yelloweye in the 2016-2017 seasons.
Catch ratios (which measure the actual change in catches prior to and post the TAC reduction) closely matched the TAC value with a ratio of -0.32. This negative catch ratio demonstrates that skippers reduced their actual Yelloweye catch to match the reduction in TAC, i.e., similar TAC and catch ratios demonstrate that the Halibut fleet had an incentive to avoid Yelloweye and also the ability to reduce their catch of Yelloweye. Establishing that the Halibut fleet had an incentive to avoid Yelloweye and that they successfully avoided exceeding TAC allocations indicates that skippers are employing successful Yelloweye avoidance behaviour in their fishing strategies. These strategies will be discussed further in section 5.1.7.

5.1.5 What are the differences in spatial and seasonal fishing patterns before and after the 2016 reduction of the Yelloweye TAC?

Initially, I examined the inter-annul patterns of the whole Halibut L licence fleet by examining number of fishing sets, number of skippers and number of vessels from 2007-2017. All of these figures show similar trends to the Halibut TAC allocation. This is rational, as the amount of ‘catchable’ fish has decreased since the 2007 and 2008 seasons. As the Halibut TAC stabilized, so did the number of skippers, vessels and fishing sets. There was noticeable reduction in the number of sets, skippers and vessels hailing out on the L licence in 2014. This may be due to a number of factors, such as the introduction of the ability of skippers to hail-out on different licences while targeting Halibut, but these factors are outside the scope of this thesis, as only L licence fishing effort were examined in this study.

Analysis of logbook data prior and post Yelloweye TAC reduction indicated that some skippers have shifted to sets that do not encounter Yelloweye, into deeper water in post years. Fishing grounds have consolidated in post years into smaller areas compared to prior years, possibly reflecting skipper’s reluctance to set gear in unfamiliar areas, potentially encountering high proportions of Yelloweye. A clustering approach developed by Branch et. al (2005) was adapted for the Halibut fishery. Fishing opportunities were categorized by bounded utilization ratios as Abandoned (Category 1), Negative (Category 2) and Positive (Category 3). There were no New (Category 4) fishing opportunities. The mean proportion
of Yelloweye landed by the top 80 skippers was greater in Category 2 (negative) than in Category 3 (positive utilization ratio), in the spring. This indicates that the ‘negative’ fishing opportunities had the highest Yelloweye encounters and the ‘positive’ fishing opportunities (i.e., those that are being utilized more since the Yelloweye TAC reduction), had fewer Yelloweye encounters. This finding is consistent with the interview responses to the question “why do you abandon fishing areas”, which included: 1) because there wasn’t enough Halibut to make it worthwhile; 2) because there was too much Yelloweye; and 3) because I caught my Halibut elsewhere and didn’t need to return to those grounds. Responses 1 and 3 are effectively the same, as fishermen would have chosen the more efficient Halibut fishing grounds over the less efficient areas.

Scatterpie plots of catch compositions in fishing opportunities of the top 80 skippers are consistent with the interview findings. Some fishing opportunities in Category 1 (abandoned) had high proportions of Yelloweye catch (as expected), but others unexpectedly had high proportions of Halibut. This suggests that a skipper’s reasons for abandoning fishing opportunities, or utilizing them less, could not be attributed only to high encounter rates of Yelloweye and that there are other motivating factors. By comparing data patterns with the interview analysis, I was able to better understand the data, as it is rational to assume that skippers would only abandon fishing opportunities that had undesirable catch compositions. However, interviews revealed a multitude of reasons for abandoning or decreasing utilization of fishing opportunities. Section 4.6.1 explored these influences on fishing behaviour, which can be collective as well as individual. My Four Quadrant Integral Theory model, adapted from Wilber’s (1998) work, explored each behaviour-influencing factor as might be experienced by an individual and by the fleet as a whole. This model is adaptable to new information as more skippers are interviewed and can be used to aid in developing management strategies so fisheries managers can better understand what may drive fishers’ behaviours at sea. Fishers’ behaviour at sea is an important aspect of fisheries management (Poos et al., 2010) but has often been overlooked in the field of fisheries science (Branch & Hilborn, 2008; Salas & Gaertner, 2004). Social aspects of fishing behaviour can be better understood by engaging stakeholders and integrating quantitative and qualitative analysis. This mixed method research approach (Onwuegbuzie et al., 2017) is especially valuable to the study of fisheries management where individual skippers’ experiences and perspectives can be greatly divergent and
highly site- (or season-) specific, which influences their fishing behaviour (Pascoe et al., 2009). I was able to directly ask skippers why they abandoned certain fishing opportunities or why they chose to fish in different depths/seasons by presenting skippers with maps of their fishing effort and letting them describe their experiences at sea. Fishers who revisit fishing opportunities inter- or intra annually can predict, to a certain extent, what might be encountered there and therefore return to areas in which they encounter an assemblage of fish that matches their desired fishing strategies. Areas that fishers avoid or abandon altogether, can be therefore predicted to have an “undesirable” assemblage of species, in terms of the combination of species quota held (Branch & Hilborn, 2008; Pelletier & Ferraris, 2000).

The use of the base case 2007-2017 (or 2007-2015 as prior years) was chosen following recommendations from active skippers to utilize as much data as possible to establish trends prior to the Yelloweye reductions in the 2016 fishing season. These years were chosen as the base case because they incorporate a longer time period which helps mitigate external variables such as changes in Halibut TAC, weather and markets and any influences they may have on fishing behaviour. 2009-2015 was chosen as a sensitivity case because the Halibut TAC more or less stabilized during those years until 2017, and even more so between 2012 and 2017. The period 2014-2015 was also chosen because it offers an equal prior and post year comparison (two years in both prior and post). Not surprisingly, the sensitivity case with prior years 2014-2015 had the weakest trends in seasonal differences compared to the base case as it utilized a much smaller time period during which fewer skippers were active and fewer sets were made. However, for the other two sensitivity cases, trends among the three categories and between the two seasons were similar to the base with prior years 2007-2015. Even though this is a multispecies fishery, Halibut is the target species for most skippers. While these sensitivity analyses was performed to test for sensitivity to effects of changes in Halibut TAC, the focus of this thesis is on the potential effects of Yelloweye TAC reduction in particular. The choice of the longest time period for prior years allowed was considered most informative in terms of analysing shifts in behaviour due to the emergence of Yelloweye as a choke species in 2016.
### 5.1.6 Seasonal shifts and choke species

Following section 5.1.4, the fourth major finding of this study is that there appear to be two main types of Halibut fishers: spring-specialist fishers (21% of top 80 skippers made the majority of their sets (≥60%) in spring months), and summer-specialist fishers (61% of the top 80 skippers made the majority of their sets (≥60%) in summer months). Seasonal fishing effort patterns based on annual biomass cycles have been observed before in other fisheries, such as the French Guyana shrimp fishery (*Penaeus subtilis*) (Garcia, Lemoine, & Le Brun, 1985), and while the Halibut depth migration has been extensively studied (Loher, 2008, 2011; Loher & Blood, 2009; Loher & Seitz, 2006, 2008; Seitz, Loher, Norcross, & Nielsen, 2011), the seasonal division of fishing behaviour of the B.C. Halibut fishers has not been studied.

Based on the composition of their catch and depth of their fishing opportunities, I predict that spring specialists should not be notably affected by further potential reductions in Yelloweye TAC because the majority of their sets are made outside the Yelloweye depth range. Conversely, I predict that summer specialists will be notably impacted by further potential reductions in Yelloweye TAC because the majority of their sets are made within Yelloweye depth range, in shallow continental shelf waters. These skippers may be limited in their future ability to catch their allocated Halibut quota due to encounters of Yelloweye causing them to exceed available quota. It follows that that summer skippers may have an incentive to abandon their summer fishing opportunities in favour of spring fishing opportunities to balance their objectives (targeting Halibut) and constraints (avoiding Yelloweye) (Béné, 1996).

According to skippers interviewed, so far a number of summer-specialized skippers have been able to find enough Yelloweye quota to lease to cover their overages, through personal connections, carry-over allowances and combination trips within the groundfish sector. Most of the skippers interviewed expressed anxiety about future Yelloweye reductions. One spring-specialized skipper said they no longer target Yelloweye because the fish buyers, who control the leasing of some of the Yelloweye quota, need to utilize it for the summer-specialized skippers who encounter a high abundance of incidental Yelloweye.
Four skippers expressed concern that their ability to carry over or lease Yelloweye quota would not carry into the 2018 season and they would be forced to abandon fishing opportunities to seek new areas where there were fewer Yelloweye. The skippers interviewed who fished in shallow waters in the summer, predicted that further Yelloweye TAC reductions may force them to shift their seasonal fishing strategies from summer months to spring months to avoid Yelloweye. Fisher knowledge of fishing grounds can be highly spatially and temporally specialized (Fulton et al., 2011). Interviewed skippers considered this would be a drastic tactic as it would involve discarding all of their acquired summer fishing experiential knowledge and having to learn different spring fishing areas and strategies. This balance between fulfilling the fishers’ objectives (landing their Halibut quota) and their constraints (avoiding Yelloweye encounters) described by Béné (1996) is what drives fishers’ spatio-temporal behaviours (Béné, 1996). I recommend repeating my analyses when data are available from the 2018 and 2019 fishing seasons, to test whether larger shifts away from shallow spring fishing seasons occur following further planned reductions in Yelloweye quota.

Analysis of fisheries data over the course of this study indicated that, while the total number of sets in 2016 and 2017 has remained relatively stable, the number of fishing opportunities has decreased since the Yelloweye TAC reduction. This likely indicates that skippers are potentially setting fewer exploratory sets and consolidating their sets into known fishing grounds with predictable (to a certain extent) catch compositions. Because of the effect of the choke species, skippers are limited in their ability to try out new areas. Fishing in areas that are proven fishing grounds, skippers have a picture of what they might catch (Branch & Hilborn, 2008; Jannot & Holland, 2013), but trying a new area might result in the encounter of so many Yelloweye that the boat will not be able to continue fishing for the year, and they will therefore not be able to access their Halibut quota (i.e., choke species as described by Schrope (2010)). This is a problem at the individual level, where a skipper having to sit out the fishing season means the crew lose their jobs for the year. If this happens to a small number of skippers, their Halibut quota can be leased out to others who can successfully avoid Yelloweye (or have enough quota), but if this occurs on a large scale then there may be economic implications as the commercial Halibut fleet may not being able to access their Halibut quota due to an abundance of Yelloweye present on the fishing grounds. The majority of commercial fishing opportunities since 2007 were not
utilized in 2016 and 2017, but if we compare this with number of sets deployed annually is possible to see large fluctuations that do not correspond with the steady reduction of fishing opportunities. This indicates that skippers are shifting their fishing effort among fishing opportunities, e.g., from summer to spring. Skippers may also shift away from a fishing opportunity if they arrive after it has been fished recently by another vessel, and therefore does not have enough Halibut to justify staying. In both of these hypothetical examples, the skipper, having tried their regular fishing opportunities and not finding sufficient catch, must move on and make more sets elsewhere. In examining patterns of the total number of fishing opportunities for the top 80 skippers, the largest inter-annual difference was 50 fishing opportunities, which is less than one new fishing opportunity for each of the top 80 skippers in a year. According to one skipper: “this might be the difference between having to set your gear with other boats around (competition for the fishing grounds) or having it all to yourself” (where you are able to spread your gear out over multiple sets). These trends can be highly annually and seasonally specific and are most accurately interpreted through a combination of interviews with active fishers and quantitative analysis, similar to the methods employed by Mortesen (2018) on North Sea trawlers, to better understand the fine-scale fishing tactics employed by skippers to manage choke species encounters.

5.1.7 Avoidance behaviours

Three types of Yelloweye avoidance fishing behaviours were identified: 1) a shift into deeper waters, outside Yelloweye depth range seen in both spring and summer seasons; 2) abandoning fishing opportunities with high catch proportions of Yelloweye but do not explore new fishing grounds; and 3) shift fishing seasonally to adjust proportion of landed Yelloweye.

A shift into deeper waters was demonstrated by plotting Halibut set depths for years prior and years post the Yelloweye TAC reduction. Scatterpie plots were also demonstrative of individual skippers who shifted into deeper waters outside of Yelloweye depth range. Scatterpie plots demonstrated that the catch composition of many abandoned fishing opportunities had high proportions of Yelloweye catch. Furthermore, there was a higher mean proportion of landed Yelloweye in Category 1 and Category 2 fishing opportunities than in Category 3 fishing opportunities, indicating that fishing opportunities that were
abandoned or had decreased utilization had a greater proportion of Yelloweye than those where utilization had increased. This was statistically significant verified by running the Kruskal-Wallice rank sum test (see Sections 3.8.1 and 4.5.1).

Total landed weight of Yelloweye was compared between spring and summer. There was consistently more Yelloweye caught in the summer than the spring, which is expected because the majority of fishing activity in the summer takes place within the depth range of Yelloweye rockfish habitat. Analysis of the proportion of Yelloweye landed in spring and summer showed that, while the proportion of Yelloweye landed in the spring was reduced, the proportion landed in the summer increased slightly. Interviewed skippers reported reducing their Yelloweye targeting behaviours in the spring. One spring-specialized skipper, when asked why they abandoned fishing opportunities with high proportions of Yelloweye, answered that the fish buyer no longer offers to lease Yelloweye quota to them in the spring (as this skipper does not have a large amount of Yelloweye quota themself), nor has the buyer requested they seek-out catches of Yelloweye in the years post Yelloweye reductions, whereas they were asked to target Yelloweye in years prior. It can be assumed that this quota was subsequently leased to summer skippers who encounter a greater proportion of incidental Yelloweye catch, to enable them to continue fishing for Halibut.

I recommend a future study into the fish buyer/processers’ influence on skippers’ behaviour regarding species catch composition and species-specific targeting behaviours. Interviews should be conducted with fish buyers and processors to better understand the dynamics of bycatch quota leasing. I believe this study would also elucidate details about the trade-offs regarding targeting different sizes of Halibut, as skippers reported catching large Halibut in the summer and small Halibut in the spring. This size difference may also be a reason more skippers have not shifted their seasonal fishing effort from summer (where larger landed Halibut reportedly fetch a higher price from the fish buyers) to spring (where smaller Halibut fetch a lower price). Historical Halibut size-price scales would have to be quantified. The influence of fish buyers on fishing behaviour surfaced many times during the interviews, especially from skippers who leased a portion of their quota.
5.1.8 Unexpected results

The first unexpected result of the study was that, while skippers demonstrated an ability to avoid catches of Yelloweye, the results of this avoidance behaviour were not strongly evident in utilization of fishing opportunities. Skippers in the Halibut hook and line fleet were found to have more abandoned fishing opportunities than those where they increased utilization. This is contrary to Branch and Hilborn’s (2008) findings for the groundfish bottom trawl fleet, which found 45% of fishing opportunities were classified as new (utilization ratio of 1) and only 0.8% were classified as abandoned (Branch & Hilborn, 2008; Branch et al., 2005). Possible explanations for the disparity between my findings and previous studies include the possibility that skippers were able expand known fishing opportunities by extending their sets into deeper waters instead of finding completely new fishing grounds. If this occurred within the defined cut point distance, these sets would still be classified as being in the same fishing opportunity. This is rational, risk averse behaviour, expanding known sets instead of exploring new ones, as exploratory fishing in the presence of choke species can be seen as too risky. Interviewed skippers reported having a disincentive to go exploratory fishing, as encounters of too many Yelloweye could stop their Halibut fishing for the year. A study on fleet dynamics and fisher behaviour by Branch et al., (2006) divided fishers into “risk-loving” and “risk-averse” groups; they theorized the significant gains that may be associated with exploratory fishing in new fisheries would attract and benefit “risk-loving” fishers while the risk-averse fishers would have an aversion to exploration in the face of uncertain catch compositions in established fisheries (Branch et al., 2006). Having existed on the B.C. coast since the late 1880s (Jones & Bixby, 2003), this commercial fishery certainly qualifies as an established fishery according Branch et al. (2006) and it is rational for Halibut fishers on the B.C. coast to fall into the “risk-averse” group in the face of Yelloweye as a choke species.

The second unexpected result of this study was the weak spatial and temporal avoidance fishing trends. I expected, at the beginning of this study, that the notable reduction in Yelloweye TAC would have caused much more apparent shifts in spatial and temporal behaviours. My results indicated identifiable but weak spatial and temporal avoidance fishing trends, evidenced by the effective fishing ground maps, examination of the scatterpie plots exhibiting the catch composition of individual skippers as a function of utilization ratios, and examination of attributes of different categories of fishing
opportunities. The weak patterns can be partially attributed to the carry-over allowance of up to 30% of unfished Yelloweye quota through to the next fishing season (DFO, 2015a). Through the interviews, multiple skippers mentioned being able to carry on, short-term, with their traditional fishing strategies despite Yelloweye quota reductions because they were able to cover their Yelloweye catch with this carried over quota. Another possible explanation for the weak trends is that skippers who previously targeted Yelloweye (instead of catching Yelloweye incidentally) stopped targeting them and simply leased their Yelloweye quota, or the fish buyers reallocated leased quota, to skippers who needed it to keep fishing for Halibut in shallower waters during summer months. Under this prediction, as the Yelloweye TAC was reduced, so was Yelloweye targeting behaviour, making more Yelloweye quota available to those who needed it to catch their Halibut. Further analysis of quota transfer transactions would be needed to verify this explanation, as well as repeating my analyses following any 2018 and 2019 TAC reductions.

5.1.9 Study limitations

The main limitation of this study is the time I had available to do the analyses. The large amount of data and complexity of the tools available for analyses far exceed the limited time period and scope of this study. Further research projects building on the foundation this thesis developed are already in progress at the Pacific Biological Station in Nanaimo and will continue over the next two years. Another limit of this study is that it was conducted only two years after the reductions were put in place and, as explained above, the 30% carry over allowance has most likely dampened expected spatio-temporal shifts. The quota carry-over allowance creates a lag effect for the impact of Yelloweye as a choke species on the spatio-temporal behaviour of the Halibut commercial hook and line fleet. This study should be revisited in the years 2018-2020 to capture the full spatial and temporal shifts associated with Yelloweye as a choke species as further TAC reductions occur. Another major limitation of this study was the small sample size of skippers interviewed. Five skippers were too few to draw any conclusive results. However, despite the small number of interviewees, the interviews included in this study were of critical importance, as they demonstrated there are a multitude of factors that may affect where skippers choose to set their gear and each skipper has a unique story to tell. Interviews were also important because it gave active fishers the opportunity to participate in research
of their fishery, with which they are intimately acquainted and about which they have important knowledge that might not be apparent in the data analysis. Consultation and collaboration with stakeholders is an important part of investigating the behaviour of fishers and the resulting effects on fish stocks, yet it is one field of research that is often overlooked in fisheries management (Branch & Hilborn, 2008; Poos et al., 2010; Salas & Gaertner, 2004; Walters & Martell, 2004).

Complicating this analysis is fishers’ ability to lease Yelloweye quota from other fishery sectors. One skipper who was interviewed mentioned fishing on a ZN licence (Rockfish) to cover rockfish catches, another reported having to lease ZN quota to cover Yelloweye catches in the Halibut fishery. Skippers also have the ability to ‘hail out’ on multiple licences to target multiple species (for example Halibut fishers reported hailing out on a Sablefish licence at the same time as their Halibut licence to be able to fish both species concurrently). These behaviours were not included in the scope of this thesis. Because of the structure of the Integrated Groundfish Management Plan and the ability to lease and transfer quota between fishing sectors, it is difficult to analyse the species caught under a single licence category. I recommend that future studies should increase the scope of licence categories to include the Sablefish, Rockfish and Lingcod hook and line sectors.

Future studies should include the incorporation of the trade-offs associated with Halibut size and price. Multiple skippers identified this as an important motivating factor of why they chose to fish in a specific season. In addition, a market analysis of the economics of the fishery should be undertaken to include the influence of fish buyers who, as reported in the interviews, are a deciding factor in what species skippers choose to target. Prices and markets for the target species, as well as bycatch species and lease prices for both, should be included in this future research opportunity.

5.1.10 Implications of major findings

The four major findings of this thesis are: 1) Yelloweye is a choke species within the Halibut commercial L licence fleet; 2) there are distinct differences between spring and summer fishing seasons; 3) these seasonal differences mean there are distinct groups of skippers who will be; to a greater or lesser extent; affected differently by further expected
Yelloweye reductions; and 4) skippers are successfully avoiding Yelloweye through a variety of techniques.

Defining specific criteria for the identification of choke species is important not only within the B.C. Halibut fishery, but for defining and dealing with choke species worldwide. Due to the increasing implementation of discard bans around the world, and specifically within the European Union under the Common Fisheries Policy (European Union, 2016; European Union Common Fisheries Policy Landing Obligation Regulations, 2015), choke species are becoming a problem for fishers and fisheries managers (Baudron & Fernandes, 2015; Reeves & Davie, 2017; Schroepe, 2010; Zimmermann et al., 2015). Through providing a set base of criteria, we can: 1) identify choke species; 2) quantify the effects they are having on fisher’s spatio-temporal behaviours; 3) identify avoidance fishing strategies; and 4) design predictive modeling tools to calculate the potential effects and the economic/environmental trade-offs of further quota reductions within multispecies fisheries. Studies such as Forrest (2008) and Forrest et al. (2015) demonstrate that ecosystem modeling can provide consistent (across different ecosystem models) and key strategic management information in light of environmental trade-offs. Bockstael & Opaluch (1983) demonstrated that modelling of fishers’ behaviour and accounting for uncertainty, provides insight into the fact that fishers’ responses to policy changes and economic incentives essentially constrain the effectiveness of fisheries managers’ decisions. The dynamic adaptability of fishers in reaction to restrictions closely mirrors Van Velan’s (1973) ‘Red Queen Hypothesis’ whereby regulators create control regulations while fishers evolve their fishing strategies to maintain economic gains. Hilborn et al. (2012) evaluated a multi-species groundfish bottom-trawl fishery and the associated trade-offs surrounding food production, profitability and conservation objectives. Similarly Jennings et al. (2012) used logbook data and landings values to examine the interactions between trawl fleets and affected marine habitats and the resulting economic and ecological trade-offs. Finally, Hatcher (2017) demonstrated the economic effects choke species can have on quota trading and lease prices in an ITQ fishery. I recommend future studies that integrate methods in the aforementioned research with my specific criteria for identifying choke species to develop predictive modeling tools using economic data on the Halibut fishery. These data should include lease prices and landings values. Such models could be used to examine trade-offs associated with seasonal behaviour, economic and
ecological factors in the presence of choke species to predict potential future behavioural shifts and impacts of the B.C. Halibut fleet.

Defining Yelloweye as a choke species highlights the challenges associated with managing multispecies ITQ managed fisheries and shows that fishers have the ability to adapt to quota reductions within certain boundaries. Identifying the spatio-temporal avoidance fishing strategies that skippers use to avoid Yelloweye while continuing to harvest Halibut will give fisheries managers a clearer picture of the implications of future reductions for Yelloweye and other species. Often there can be a knowledge gap between fisheries managers and the motivating factors that drive skippers’ behaviour at sea (Branch & Hilborn, 2008; Jennings et al., 2012; Pascoe et al., 2009). For example, Pascoe et al. (2009) suggest one of the key components of successful multi-objective modeling for fisheries management is “the need for stakeholder buy-in” (p. 427) and a commonality amongst unsuccessful fishery management systems is that they have failed to integrated complex socio-political factors into management decisions. Chambers (2016) highlighted these complexities following the introduction of ITQ fisheries systems in Iceland, and showed how social, political, and environmental changes can be perceived by fishers, which affects their decision making behaviours. Jennings et al. (2012) point out that interactions between fishers and their active fishing grounds must be assessed before debates surrounding marine environment utilization can successfully move forward. Definition of limitations of management strategies (due to fishers’ behaviour; Bockstael & Opaluch, 1983) through future modeling studies, could help fisheries managers make decisions when dealing with multispecies fisheries so that most species can be harvested economically and sustainably, or at least trade-offs can be clearly understood (Forrest et al., 2015; Hilborn et al., 2004).

Quantifying the seasonal difference between spring and summer fishing patterns within the B.C. Halibut fishery will allow researchers to further examine seasonal patterns and how they may affect the harvest policies of other fisheries. This finding was a result of interviewing skippers whose common knowledge of such seasonal differences was previously unpublished. Integrating stakeholders’ experiential knowledge using mixed methods research allows fisheries managers to gain a more detailed picture of economically and environmentally important aspects of fisheries. Identifying the group of skippers who will be affected most by future expected reductions in Yelloweye quota will provide insight into potential future impacts on fishing behaviour. The ability to predict
which skippers will need to change their fishing behaviours will allow fisheries managers to adapt incentive-based policies to effectively manage fisheries.

Further studies should focus on the effects of choke species and possible mitigation measures. Demonstrating the adaptive ability of skippers to avoid catches of Yelloweye adds to the growing base of knowledge that shows, in many cases, that skippers can be selective when given the right incentive-based fishing structures (Dunn et al., 2011; Mortensen et al., 2018). For instance Dunn et al. (2011) produced a decision tree to help facilitated management and understanding of bycatch through analytical tools (p.114) with the aim of using spatio-temporal and oceanographic characteristics collected in real-time by commercial vessels and other means to mitigate bycatch interactions through targeted dynamic, spatio-temporal fishery closures. This requires the cooperation of fishers and managers in real-time to report and interpret fishery data with the goal of avoiding bycatch species. Mortenson et al. (2018) used similar methods employed in this study to investigate the challenges associated with choke species for a North Sea trawler and successful choke species avoidance strategies by “link[ing] various sources of knowledge, bringing together fishers’ tactic knowledge at the local scale with scientists’ explicit knowledge at wider scale” (p. 10). So far, fishers within the Halibut fishery have managed to successfully adapt their fishing strategies to avoid Yelloweye and reduce their catches of this species, but the limits to these adaptive strategies has not been identified. In 2015, PECH commissioned a report on the handling and possible solutions to the choke species problems in the Baltic Sea (Zimmermann et al., 2015). One of their findings included that allowing for the ability to ‘swap quotas’ between vessels would help alleviate pressure (Zimmermann et al., 2015). This is already in place in B.C. but there is a limit to how much Yelloweye quota there is available to ‘swap’ and eventually there will likely not be enough to cover Halibut catch unless something else changes.

Implementing a regulatory framework that incentivizes fishers to act for the common good, while at the same time maximizing individual returns, is the ultimate goal of fisheries management theory (Arnason, 1994). In the history of fisheries management, the ITQ system is relatively new, having been introduced in the late 1970s and early 1980s (Annala, 1996; Arnason, 2005). The introduction of discard bans and at-sea monitoring technology that is able to accurately enforce these bans is even more recent (Condie et al., 2014; European Commission, Fisheries, 2017; FAO, 2011b). Data gained from at-sea
monitoring allows fisheries managers and scientists to gain a detailed picture of catch compositions and spatial movement of the fleet, which has not been possible until recently (Cahalan, Leaman, Williams, Manson, & Karp, 2010; Needle et al., 2015; Stanley et al., 2015). This study examines how a multispecies ITQ fishery can be impacted by a single choke species and illustrates how adaptive fishers can be when faced with TAC reductions. This is an important area of study, especially with the uncertainties associated with climate change, changes in species distribution and the successful SMART implementation of EBFM strategies as recommended by the FAO (FAO, 2011c, 2011a, 2011b).

5.2 Conclusion

This thesis employs a mixed method research design to combine a quantitative statistical analysis with qualitative, stakeholder engagement research strategies to analyse skippers’ spatial fishing behaviours and the underlying motivations for fishing behaviour. Yelloweye is a choke species within the Halibut commercial L licence fleet, within which there are distinct differences between spring and summer fishing seasons. These seasonal differences mean there are distinct group of skippers who will be, to a greater or lesser extent, affected by further expected Yelloweye reductions due to the different fishing strategies necessarily employed in each season. Halibut skippers have successfully avoided overages of Yelloweye catch through employing a variety of techniques, which may include a shift into deeper waters, seasonal fishing effort changes, limiting their fishing effort to known fishing opportunities (not exploratory fishing), and abandoning areas with high proportions of Yelloweye catches. Limits to fishers’ capacity to employ avoidance techniques while fulfilling their Halibut catch objectives have not been established. While these spatio-temporal avoidance fishing behaviours are not as pronounced in 2016 and 2017 as was expected at the beginning of this study, it is expected that stronger trends will be observed in 2018 and 2019 with the further reduction in Yelloweye quota and reduced ability to ‘carry-over’ Yelloweye quota from one year to the next (due to fishers ‘using up their Yelloweye quota in 2016 and 2017).
References


Annala, J. H. (1996). New Zealand’s ITQ system: have the first eight years been a success or a failure? *Reviews in Fish Biology and Fisheries, 6*(1), 43–62. https://doi.org/10.1007/BF00058519


Department of Fisheries and Oceans. (2015). *Proceedings of the Pacific regional peer review on the stock assessment for the outside population of Yelloweye Rockfish (Sebastes ruberrimus) for British Columbia Canada in 2014*. Pacific Biological Station, Nanaimo B.C.


DFO. (2006a). *A harvest strategy compliant with the Precautionary Approach.* (Canadian Scientific Advisory Section No. 2006/023).


DFO. (2015b). *Stock Assessment for the Outside population of Yelloweye Rockfish (Sebastes ruberrimus) for British Columbia, Canada in 2014* (Canadian Science Advisory Report No. 2015/060). Department of Fisheries and Oceans, Groundfish Division.


https://doi.org/10.1111/j.1467-2979.2010.00371.x


https://doi.org/10.1139/f05-247


https://doi.org/10.1890/050060


https://doi.org/10.1080/02755947.2011.591239


https://doi.org/10.1126/science.162.3859.1243

*Environmental and Resource Economics, 58*(3), 463–472. 
https://doi.org/10.1007/s10640-013-9716-1


Malcolm v. Canada (Minister of Fisheries), No. 36012 (FCA 130 November 20, 2014).


fishe
ries.
https://doi.org/10.1093/icesjms/fsp241

lois.justice.gc.ca/eng/acts/P-21/page-1.html

data in monitoring stock dynamics: Accounting for targeting behaviour in mixed
https://doi.org/10.1016/j.fishres.2007.08.016

R Core Team. (2017). R: A language and environement for statistical computing. Vienna,
project.org/

Reeves, S. A., & Davie, S. L. (2017). Quota management and choke species under the
landing obligation. Fisheries Innovation Scotland and the Centre for Environment

Reid, P. C., Fischer, A. C., Lewis-Brown, E., Meredith, M. P., Sparrow, M., Andersson, A.
https://doi.org/10.1016/S0065-2881(09)56001-4

Request for Proposal: depth stratified, random design longline research survey in southern
Association.
Richards, L. (1986). Depth and habitat distributions of three species of rockfish (Sebastes) in British Columbia: observations from the submersible PICES IV. *Environmental Biology of Fishes, 17*(1), 13–21.


Species at Risk Act, 29 § List of Wildlife Species at Risk.


https://doi.org/10.1016/j.marpol.2015.06.028


https://doi.org/10.1139/cjfas-2012-0371


https://doi.org/10.1016/j.ecolind.2006.02.009

https://doi.org/10.1126/science.1173146

Appendix A

Species listed in the Integrated Fisheries Management Plan (IFMP) 2017 as allocated to Halibut sector licence holders. It is important to note that this list does not take into account fishers’ ability to temporarily or permanently lease quota species from, or to other groundfish sectors and therefore does not include all possible species a Halibut fisher might legally retain.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Skate</td>
<td>Beringraja binoculata</td>
</tr>
<tr>
<td>Canary Rockfish</td>
<td>Sebastes pinniger</td>
</tr>
<tr>
<td>China Rockfish</td>
<td>Sebastes nebulosus</td>
</tr>
<tr>
<td>Copper Rockfish</td>
<td>Sebastes caurinis</td>
</tr>
<tr>
<td>Halibut</td>
<td>Hippoglossus stenolepis</td>
</tr>
<tr>
<td>Lingcod</td>
<td>Ophiodon elongatus</td>
</tr>
<tr>
<td>Longnose Skate</td>
<td>Raja rhina</td>
</tr>
<tr>
<td>Longspine Thornyhead</td>
<td>Sebastolobus altivelis</td>
</tr>
<tr>
<td>Quillback Rockfish</td>
<td>Sebastes maliger</td>
</tr>
<tr>
<td>Redbanded Rockfish</td>
<td>Sebastes babcocki</td>
</tr>
<tr>
<td>Rougheye Rockfish</td>
<td>Sebastes aleutianus</td>
</tr>
<tr>
<td>Sablefish</td>
<td>Anoplopoma fimbria</td>
</tr>
<tr>
<td>Shortraker Rockfish</td>
<td>Sebastes borealis</td>
</tr>
</tbody>
</table>
14  Shortspine Thornyhead  *Sebastolobus alascanus*
15  Silver Grey Rockfish  *Sebastes brevispinis*
16  Spiney Dogfish  *Squalus suckleyi*
17  Tiger Rockfish  *Sebastes nigrocinctus*
18  Yelloweye Rockfish  *Sebastes ruberrimus*
19  Yellowmouth Rockfish  *Sebastes reedi*
Appendix B

Informant interview protocol, survey questions, and informed consent form.

Interview Consent Form

Coastal and Marine Management Master's Thesis, University Centre of the Westfjords, University of Akureyri

SPERA project, Department of Fisheries and Oceans Canada

Research Investigator: Tiare Boyes

Research Participants name: ____________________________

Date: ____________________________

This interview is expected to take about an hour. We have not identified any risks associated with your participation but you have the right to halt the interview or withdraw from the research at any time.

Thank you for your participation in this survey as part of my thesis. I am writing while working at the Pacific Biological Station and for the Department of Fisheries and Oceans Canada (DFO). Ethical procedures for academic research require that interviewees explicitly agree to being interviewed and how the information contained in their interview will be used. This consent form is necessary for us to ensure that you understand the purpose of your involvement and that you agree to the conditions of your participation.

Please read the following and sign at the bottom to indicate your approval of the following:

- This interview will be recorded and transcribed and notes will be taken by during the interview.
- The transcript of interview will be analysed by Tiare Boyes as research investigator, assisted by Katherine Bannar-Martin and Robyn Forrest.
- Access to the interview transcript will be limited to staff at the Department of Fisheries and Oceans Pacific Biological Station and will require permission by Robyn Forrest.
- All documents will be kept on encrypted drives.
- Any summary interview content or direct quotation from the interview, that are made available through academic publication or other academic outlets will be anonymized so that you cannot be identified, and care will be taken to ensure that other information in the interview that could identify yourself is not revealed unless we receive your written permission to do so.
- The actual recording and your consent form will be kept for DFO records in a secure location.
- The recording will be anonymized and only available to researchers Tiare Boyes, Robyn Forrest, and Katherine Bannar-Martin.
- Participation involves being interviewed by Tiare Boyes.
- Any violation of the conditions above will only occur with your further explicit approval.

Appendix B 1: Informed consent form page 1.
Appendix B 3: Survey questionnaire page 1.
Survey Questions

6. What are your reasons for fishing during particular seasons (Spring, Summer, Fall)?
   a. I engage in other types of fishing which limits my time frame to go Halibut fishing (Tuna, Salmon, Herring etc.)
   b. I have primary experiential knowledge of a particular season (know where to set gear to find fish, what the tides are like, what weather I can expect)
   c. Halibut market prices
   d. I am limited by the size of my boat or type of gear
   e. I want to avoid certain bycatch species
   f. The buyer tells me when to go
   g. Other answers?

7. What distance do you leave between sets?

8. What are the top 5 species you encounter? (besides Halibut)
   1.
   2.
   3.
   4.
   5.

9. Other than Halibut, are there any other species under your licence you have targeted?
   a. Yes (list species)
      i.
      ii.
      iii.
      iv.
      v.
      vi.
   b. No

10. (If yes to Q.9) What makes you target these species?
    a. I have the quota to cover these species and they are part of my business model
    b. I get more money to fish them than to lease the quota
    c. Where/when I fish means I don’t encounter them incidentally so to harvest them, I need to go looking for them
    d. I’ve always done it
    e. Other answer?
Survey Questions

11. (If no to Q. 9) Why not target other species than Hali but?
   a. I catch non-target species without targeting them
   b. I can lease non-target quota I don’t use to other fishermen
   c. Other answer?

12. Have you changed your fishing strategies since 2015 when the Yelloweye quota was reduced by 32%?
   a. Yes
   b. No

13. If yes to question 12, how have you changed your fishing strategies? (where/when open answer)

14. Are you able to still catch your Hali but quota without leasing other species?
   a. Yes
   b. No

15. (If Yes Q. 14) Is this because you have changed your fishing strategies? (where/when)

16. (If No Q. 14) What species do you find necessary to lease to catch your Hali but quota?

17. Is there anything else you think is influencing where the halibut fleet fishes since integration (2006)?

Appendix B 5: Interview questionnaire page 3.
Appendix C

Set depth over time in summer months (May-August) in Area 5 sub management areas.

Appendix C 1: Depth of all Halibut sets for the B.C. L licence hook and line commercial fishery made in the summer months (May-August) separated by sub management area within Area 5. Areas 5A, B, C, D and E are included. Orange boxes denote interquartile range of set depth. Horizontal black lines indicate median depth while black dots indicate mean depth of sets.
Appendix C 2: Depth of all Halibut sets for the B.C. L licence hook and line commercial fishery made in the summer months (May-August) separated by sub management area within Area 5. Areas 5A, B, C, D and E are included. Coloured boxes denote interquartile range of set depth. Horizontal black lines indicate median depth while black dots indicate mean depth of sets.
## Appendix D

*Fisheries Operations Systems (FOS) for Groundfish Handbook with descriptions of data categories*

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIP_ID</td>
<td>Trip identifier; links to GF_TRIP</td>
</tr>
<tr>
<td>VESSEL_REGISTRATION_NUMBER</td>
<td>Vessel identifier issued by the Pacific Fisheries Licencing Unit, supersedes the CFV or Commercial Fishing Vessel number</td>
</tr>
<tr>
<td>DATA_SOURCE_CODE</td>
<td>Code to indicate the source of the fishing event catch data; in this table, only one record per fishing episode (set or tow) is shown with observer logbooks shown preferentially over fisher logbooks. Dockside validation records are shown for species that were landed but did not have any retained catch records in the logbook. Electronic monitoring is not included.</td>
</tr>
<tr>
<td>FISHERY_SECTOR</td>
<td>Combination of FISHERY and FISHERY_SUBTYPE but also adds a combination fishing category. Links to FISHERY_SECTOR</td>
</tr>
<tr>
<td>TRIP_CATEGORY</td>
<td>Combination of TRIP_TYPE and LICENCE_OPTION. In this field, a TRIP_TYPE of “IPHC” is considered to be the same as an “EXPERIMENTAL” trip. “IPHC” trips are also often combination trips where the vessel is retaining sablefish as part of a “QUOTA” TRIP_TYPE. To rationalize such a trip so there is only one TRIPCATEGORY, the “EXPERIMENTAL” trip type trumps the “QUOTA” TRIP_TYPE. Links to TRIPCATEGORY</td>
</tr>
<tr>
<td>F_LICENCE_IND</td>
<td>Field used to indicate (1 = true, 0 = false) if any LICENCE_PREFIX for the trip contained an &quot;F&quot; which indicates First Nations licence. Note that for combination fishing it is possible that only one of the</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>FISHING_EVENT_ID</td>
<td>Unique identifier for a fishing event (set or tow)(note that a placeholder FISHING_EVENT_ID of 0 is used for species that were landed but did not have any retained catch records in the logbook)</td>
</tr>
<tr>
<td>SKIPPER_ID</td>
<td>Identifier of the individual who is identified as the skipper for this fishing event; links to SKIPPER</td>
</tr>
<tr>
<td>BEST_DATE</td>
<td>The best available date for the fishing event (in preferential order, the fishing event end date, the fishing event start date, or the trip end date)</td>
</tr>
<tr>
<td>START_DATE</td>
<td>The date this fishing event started (from the logbook)</td>
</tr>
<tr>
<td>END_DATE</td>
<td>The date this fishing event ended (from the logbook)</td>
</tr>
<tr>
<td>START_LATITUDE</td>
<td>The latitude coordinate at the start of this fishing event (from the logbook)</td>
</tr>
<tr>
<td>START_LONGITUDE</td>
<td>The longitude coordinate at the start of this fishing event (from the logbook)</td>
</tr>
<tr>
<td>END_LATITUDE</td>
<td>The latitude coordinate at the end of this fishing event (from the logbook)</td>
</tr>
<tr>
<td>END_LONGITUDE</td>
<td>The longitude coordinate at the end of this fishing event (from the logbook)</td>
</tr>
<tr>
<td>LAT</td>
<td>The best available latitude coordinate of this fishing event formatted for GIS display (in preferential order, the start, end, or mid latitude)</td>
</tr>
<tr>
<td>LON</td>
<td>The best available longitude coordinate of this fishing event formatted for GIS display (in preferential order, the start, end, or mid latitude)</td>
</tr>
<tr>
<td>MAJOR_STAT_AREA_CODE</td>
<td>Code to indicate the Major Statistical Area that this fishing event occurred in. If the derived Major Statistical Area is null, unknown, or unspecified, the reported area code is used. Links to</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>MAJOR_STAT_AREA</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MINOR_STAT_AREA_CODE</strong></td>
<td>Code to indicate the Minor Statistical Area that this fishing event occurred in. If the derived Major Statistical Area is null, unknown, or unspecified, the reported area code is used. Links to MINOR_STAT_AREA</td>
</tr>
<tr>
<td><strong>LOCALITY_CODE</strong></td>
<td>Code to indicate the defined location with the Minor Statistical Area that this fishing event occurred in. If the derived Major Statistical Area is null, unknown, or unspecified, the reported area code is used. Links to LOCALITY</td>
</tr>
<tr>
<td><strong>DFO_STAT_AREA_CODE</strong></td>
<td>Code to indicate the statistical area defined by DFO that this fishing event occurred in; links to DFO_STAT_AREA</td>
</tr>
<tr>
<td><strong>DFO_STAT_SUBAREA_CODE</strong></td>
<td>Code to indicate the statistical subarea defined by DFO that this fishing event occurred in; links to DFO_STAT_SUBAREA</td>
</tr>
<tr>
<td><strong>BEST_DEPTH_FM</strong></td>
<td>The best available depth in fathoms for the fishing event (in preferential order, the average of the start and end depths, the mid depth, the start depth, or the end depth)</td>
</tr>
<tr>
<td><strong>START_DEPTH_FM</strong></td>
<td>The depth in fathoms at the start of this fishing event (from the logbook)</td>
</tr>
<tr>
<td><strong>END_DEPTH_FM</strong></td>
<td>The depth in fathoms at the end of this fishing event (from the logbook)</td>
</tr>
<tr>
<td><strong>GEAR</strong></td>
<td>The best available description of the general category of gear used for the fishing event (in preferential order, the gear type specified in the longline or trawl specs table, either “LONGLINE” or “TRAWL” if there is data in the corresponding longline or trawl specs table but the gear type is not specified, or the gear as defined in the OFFLOAD HEADER which is either the gear reported when the vessel hailed out or the gear that is assumed based on the fishery)</td>
</tr>
</tbody>
</table>
of the haul in number; links to GEAR

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEAR_SUBTYPE</td>
<td>The best available description of the specific subtype of gear used for the fishing event; links to GEAR_SUBTYPE</td>
</tr>
<tr>
<td>SPECIES_CODE</td>
<td>Code to indicate the species, taxonomic grouping, or object caught; links to SPECIES</td>
</tr>
<tr>
<td>SUBLEGAL_RELEASED_ROUND_KG</td>
<td>Fishing event catch in round kilograms that were identified as sublegal size and released at sea</td>
</tr>
<tr>
<td>LEGAL_RELEASED_ROUND_KG</td>
<td>Fishing event catch in round kilograms that were identified as legal size and released at sea</td>
</tr>
<tr>
<td>TOTAL_RELEASED_ROUND_KG</td>
<td>Fishing event catch in round kilograms that were identified as released at sea (includes legal, sublegal, and unidentified releases)</td>
</tr>
<tr>
<td>RETAINED_ROUND_KG</td>
<td>Fishing event catch in round kilograms that were identified as retained at sea.</td>
</tr>
<tr>
<td>BEST_RETAINED_ROUND_KG</td>
<td>The best available estimate of fishing event catch in round kilograms that were identified as retained at sea. The estimate is the logbook retained weight if it is greater than 0, the retained count multiplied by the best available average weight for that species. The average weight is taken from 1) the average individual weight of offloaded fish based on the number of fish counted at offload for this trip; or 2) the average individual weight of offloaded fish based on the number of fish retained for this trip (when the offloaded fish were not counted and all records of retained fish were counted); or 3) the average individual weight of the species landed in the same season as the trip; or 4) the average individual weight of the species landed in all seasons. *Note that a default average weight of 1 was used as the 5th option until Sept 2010 when it was removed due to the misleading “best” estimates it caused. *</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LANDED_ROUND_KG</td>
<td>This is the official retained catch weight. The best fishing event retained catch weight (as defined above) pro-rated by the ratio of the total offloaded weight to the trip total of best fishing event retained catch weights.</td>
</tr>
<tr>
<td>SUBLEGAL_RELEASED_COUNT</td>
<td>Fishing event catch in number of fish that were identified as sublegal size and released at sea. Note that this does not include liced fish.</td>
</tr>
<tr>
<td>LEGAL_RELEASED_COUNT</td>
<td>Fishing event catch in number of fish that were identified as legal size and released at sea. Note that this does not include liced fish.</td>
</tr>
<tr>
<td>SUBLEGAL_LICED_COUNT</td>
<td>Fishing event catch in number of fish that were identified as sublegal or unmarketable size and liced (amphipod damaged). Liced fish are released at sea.</td>
</tr>
<tr>
<td>LEGAL_LICED_COUNT</td>
<td>Fishing event catch in number of fish that were identified as legal or marketable size and liced (amphipod damaged). Liced fish are released at sea.</td>
</tr>
<tr>
<td>SUBLEGAL_BAIT_COUNT</td>
<td>Fishing event catch in number of fish that were identified as sublegal or unmarketable size and used as bait. Fish used for bait are not released but are also not retained to be landed.</td>
</tr>
<tr>
<td>LEGAL_BAIT_COUNT</td>
<td>Fishing event catch in number of fish that were identified as legal or marketable size and used as bait. Fish used for bait are not released but are also not retained to be landed.</td>
</tr>
<tr>
<td>RETAINED_COUNT</td>
<td>Fishing event catch in number of fish that were identified as retained at sea. Note that this does not include fish used for bait.</td>
</tr>
<tr>
<td>BEST_RETAINED_COUNT</td>
<td>The best available estimate of fishing event catch in number of fish that were identified as retained at sea. The estimate is the logbook number of fish if it is greater than 0, or the retained weight</td>
</tr>
</tbody>
</table>
divided by the best available average weight for that species. The average weight is taken from 1) the average individual weight of offloaded fish based on the number of fish counted at offload for this trip; or 2) the average individual weight of offloaded fish based on the number of fish retained for this trip (when the offloaded fish were not counted and all records of retained fish were counted); or 3) the average individual weight of the species landed in the same season as the trip; or 4) the average individual weight of the species landed in all seasons. Note that a default average weight of 1 was used as the 5th option until Sept 2010 when it was removed due to the misleading “best” estimates it caused.

| LANDED_COUNT | This is the official retained catch count. The best fishing event retained catch count (as defined above) pro-rated by the ratio of the total offloaded count to the trip total of best fishing event retained catch counts. |