In the past, sharks, skates and ray species have mainly occurred in incidental fisheries. Now they are increasingly being directly targeted due to the depleted status of traditionally targeted species. The life history characteristics of many elasmobranch species make them more sensitive to high rates of fishing mortality. The combination of these factors has resulted in the known local depletion of several elasmobranch species; including the barndoor skate, Raja laevis, of the Northwest Atlantic and the common skate, Raja batis, of Irish Sea. The longnose skate, Raja rhina, occurs commonly as incidental catch in trawl fisheries off the coast of California, Oregon and Washington. Commercial landings of skates, including R. rhina, have increased dramatically along the U.S. West coast. The objectives of this study have been to calculate accurate growth and maturity parameters for Raja rhina in order that the vulnerability of this species to fishing mortality can be assessed. The slow growth rates (k = 0.04 to 0.06) and late ages-at-50% maturity (11 to 16 years with maximum ages between 15 and 22 years, depending on sex and region) which
were calculated indicate that this species may be at great risk of depletion in the future. Survey biomass trends indicate that *R. rhina* populations have remained stable over the past twenty years. However, the possibility that biomass levels in the distant past were much higher than they are at present cannot be ruled out. It is recommended that the collection of fishery-dependent data for this species and other skate species begins immediately. This information, along with the results found in this are needed for a proper assessment for *Raja rhina*, so that the effects of current fishing pressures can be evaluated and regulated appropriately.
Age, Growth and Maturity of the Longnose Skate (*Raja rhina*) for the U.S. West Coast and Sensitivity to Fishing Impacts

by

Josie E. Thompson

A THESIS submitted to Oregon State University in partial fulfillment of the requirements for the degree of Master of Science

Presented September 6, 2005
Commencement June 2006
Master of Science thesis of Josie E. Thompson
presented on September 6, 2005.

APPROVED:

Redacted for privacy

Major Professor, representing Marine Resource Management

Redacted for privacy

Dean of the College of Oceanic and Atmospheric Sciences

Redacted for privacy

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Redacted for privacy

Josie E. Thompson, Author
ACKNOWLEDGEMENTS

I would like to thank those who have supported me throughout my graduate experience at Oregon State University and the Hatfield Marine Science Center (HMSC):

- the Cooperative Institute for Marine Resources Studies (CIMRS), Clare Reimers, Jessica Waddell and the NOAA Fisheries Northwest Fisheries Science Center for continuous funding and support of this research.
- Wade Smith and the Ichthyology Lab at Moss Landing Marine Laboratories (MLML) for their guidance and assistance with age structure preparation techniques and ageing methods.
- my major professor, Scott Heppell, for his patience, useful advice and for enabling me to pursue this research with a great amount of independence.
- my graduate committee members for their guidance; Michael Schirripa, for his support and encouragement and his expertise in fish ageing research, and Douglas Markle for sharing his knowledge of fish life history.
- Keith Bosley and Victor Simon, and the West Coast Groundfish Survey Team for their support in the collection of data and their enthusiasm for my research.
- the NOAA Fisheries Ageing Lab in Newport for their willingness to share lab space, for their great level of expertise, and for their friendship.
- Waldo Wakefield for always believing in the importance of this research and continually communicating this belief to the Northwest Fisheries Science Center.
- Beth Horness of the Fisheries Resource Analysis and Monitoring Division (FRAMD) of NOAA Fisheries for providing 2003 West Coast Groundfish survey data.
- the Heppell Lab, including Selina Heppell, for their support, guidance and understanding. Special thanks to Abby, Brooke, Tad and Paola.
- Dave Wright, Wild and the Pacific Seafood processing plant employees for giving me full access to their commercial skate landings, thus greatly assisting with the port data collection process.

- Mark Karnowski and Mark Freeman at the Oregon Department of Fish and Wildlife for providing me with Oregon trawl logbook information.

- my loving family in Arizona, who have always given me their whole-hearted support for everything I do.

- to Cristen, Patrick, Mary, Mitch, Kathleen, and Toby for all the good times and for being such a solid group of friends, with a special thanks to Kate for her encouragement, care and inspiration.

- to my parents, Linda and Tyler for instilling in me a great sense of appreciation and wonder for the interconnectedness and beauty of life on Earth.

- Special thanks to my mom, for forever being my biggest fan and cheerleader.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Introduction</td>
<td>2</td>
</tr>
<tr>
<td>Age and growth of the longnose skate, <em>Raja rhina</em>, for Washington, Oregon and California</td>
<td>6</td>
</tr>
<tr>
<td>Abstract</td>
<td>7</td>
</tr>
<tr>
<td>Introduction</td>
<td>8</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>15</td>
</tr>
<tr>
<td>Results</td>
<td>26</td>
</tr>
<tr>
<td>Discussion</td>
<td>54</td>
</tr>
<tr>
<td>Reproduction and maturity of the longnose skate, <em>Raja rhina</em>, for Washington, Oregon and California</td>
<td>62</td>
</tr>
<tr>
<td>Abstract</td>
<td>63</td>
</tr>
<tr>
<td>Introduction</td>
<td>64</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>66</td>
</tr>
<tr>
<td>Results</td>
<td>71</td>
</tr>
<tr>
<td>Discussion</td>
<td>94</td>
</tr>
<tr>
<td>Evaluation of current U.S. west coast fisheries data for the longnose skate, <em>Raja rhina</em></td>
<td>98</td>
</tr>
<tr>
<td>Introduction</td>
<td>100</td>
</tr>
<tr>
<td>Fisheries-Dependent Information</td>
<td>101</td>
</tr>
<tr>
<td>Fisheries-Independent Information</td>
<td>118</td>
</tr>
<tr>
<td>Discussion</td>
<td>132</td>
</tr>
<tr>
<td>General Conclusions</td>
<td>135</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bibliography</td>
<td>137</td>
</tr>
<tr>
<td>Appendices</td>
<td>146</td>
</tr>
<tr>
<td>Appendix A. Definition of clarity ratings (1-5) used in this study to</td>
<td>147</td>
</tr>
<tr>
<td>define the readability of each centrum section</td>
<td></td>
</tr>
<tr>
<td>Appendix B. Guidelines established by Josie Thompson and Wade Smith</td>
<td>147</td>
</tr>
<tr>
<td>for ageing <em>Raja rhina</em> vertebral centrum thin-sections</td>
<td></td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Photo of whole centra stained by the methods of Hoenig and Brown (1988).</td>
<td>18</td>
</tr>
<tr>
<td>2.</td>
<td>Definition of an annulus as a pair of one light and one dark band.</td>
<td>21</td>
</tr>
<tr>
<td>3.</td>
<td>Number of male and female <em>Raja rhina</em> sampled during the 2003 West Coast groundfish survey data collection for each 10 cm total length bin.</td>
<td>26</td>
</tr>
<tr>
<td>4.</td>
<td>A map of the five designated International Northern Pacific Fisheries Council (INPFC) fisheries management regions as defined by latitude (PFMC 1997).</td>
<td>28</td>
</tr>
<tr>
<td>5.</td>
<td>Number of male and female <em>Raja rhina</em> by 10 cm size class collected from landings made in the port of Newport, Oregon.</td>
<td>30</td>
</tr>
<tr>
<td>6.</td>
<td>Number of male and female <em>Raja rhina</em> collected each month from landings made in the port of Newport, Oregon, between February 2003 to November 2004.</td>
<td>31</td>
</tr>
<tr>
<td>7.</td>
<td>Start and finish locations and depths for all commercial catches (excluding one sample) landed and sampled in the port of Newport, Oregon (Oregon coast border in red).</td>
<td>32</td>
</tr>
<tr>
<td>8.</td>
<td>Comparison between reader 1’s first and second reads for the initial intra-comparison study.</td>
<td>34</td>
</tr>
<tr>
<td>9.</td>
<td>Percent agreement results by age class for the initial intra-comparison study.</td>
<td>35</td>
</tr>
<tr>
<td>10.</td>
<td>Coefficient of variation results by age class for the initial intra-comparison study.</td>
<td>35</td>
</tr>
<tr>
<td>11.</td>
<td>Comparison between reader 1’s first and second read for the second intra-comparison study.</td>
<td>36</td>
</tr>
<tr>
<td>12.</td>
<td>Percent agreement results by age class for the second intra-comparison study.</td>
<td>37</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>13.</td>
<td>Coefficient of variance results by age class for the second intra-comparison study</td>
<td>37</td>
</tr>
<tr>
<td>14.</td>
<td>Comparison between reader 1’s first read and reader 2’s first read for the initial inter-comparison</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>study</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Percent agreement results by age class for the initial inter-comparison study</td>
<td>39</td>
</tr>
<tr>
<td>16.</td>
<td>Coefficient of variation results by age class for the initial inter-comparison study</td>
<td>39</td>
</tr>
<tr>
<td>17.</td>
<td>Comparison between reader 1 and reader 2 for the second inter-comparison study</td>
<td>40</td>
</tr>
<tr>
<td>18.</td>
<td>Percent agreement for each age class for the second inter-comparison study between reader 1 and reader</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Calculated coefficient of variation by age class for the second inter-comparison study between reader</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>1 and reader 2</td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Inter-comparison results between reader 1 and reader 3</td>
<td>42</td>
</tr>
<tr>
<td>21.</td>
<td>Percent agreement for each age class between reader 1 and reader 3</td>
<td>43</td>
</tr>
<tr>
<td>22.</td>
<td>Calculated coefficient of variation by age class for the intercomparison between reader 1 and reader 2</td>
<td>43</td>
</tr>
<tr>
<td>23.</td>
<td>Number of samples compared for each age class in the intercomparison between reader 1 and reader 3</td>
<td>44</td>
</tr>
<tr>
<td>24.</td>
<td>A comparison of von Bertalanffy growth curves using age data from the second intercomparison study</td>
<td>45</td>
</tr>
<tr>
<td>25.</td>
<td>Photo of a vertebral centra thin-section taken from a 1-year-old <em>R. rhina</em> with birth indicator noted</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>(arrow)</td>
<td></td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>26.</td>
<td>Relative marginal increment ratio calculations for <em>Raja rhina</em> collected from fisheries landings during 2003 to 2004.</td>
<td>44</td>
</tr>
<tr>
<td>27.</td>
<td>Centrum edge classification by date for <em>Raja rhina</em> sections collected from fisheries landings during 2003 and 2004.</td>
<td>45</td>
</tr>
<tr>
<td>28.</td>
<td>The relationship between disc width and total length for all males and females.</td>
<td>49</td>
</tr>
<tr>
<td>29.</td>
<td>The relationship between log-transformed weight and log-transformed disc width for both sexes.</td>
<td>50</td>
</tr>
<tr>
<td>30.</td>
<td>The relationship between log-transformed weight and log-transformed disc width for individuals North and South of Cape Mendocino.</td>
<td>51</td>
</tr>
<tr>
<td>31.</td>
<td>The relationship between age and growth for male and female <em>Raja rhina</em> with the fitted 2 parameter VBGF.</td>
<td>53</td>
</tr>
<tr>
<td>32.</td>
<td>The relationship between age and growth for <em>Raja rhina</em> collected north and south of Cape Mendocino and the fitted 2 parameter and 3 parameter VBGF for each region.</td>
<td>53</td>
</tr>
<tr>
<td>33.</td>
<td>Photographs of immature (a) and mature (b) male <em>Raja rhina</em> as defined in this study.</td>
<td>70</td>
</tr>
<tr>
<td>34.</td>
<td>Photographs of immature (a) and mature (b) female <em>Raja rhina</em> as defined in this study.</td>
<td>71</td>
</tr>
<tr>
<td>35.</td>
<td>The relationship between clasper length and total body length for immature and mature males found North of Cape Mendocino (including all survey and commercial samples).</td>
<td>74</td>
</tr>
<tr>
<td>36.</td>
<td>The relationship between clasper length and total body length for immature and mature males found South of Cape Mendocino (survey samples only).</td>
<td>74</td>
</tr>
<tr>
<td>37.</td>
<td>The relationship between sperm duct width and total length for immature and mature males caught North of Cape Mendocino.</td>
<td>76</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>38</td>
<td>The relationship between sperm duct width and total length for immature and mature males caught South of Cape Mendocino</td>
<td>76</td>
</tr>
<tr>
<td>39</td>
<td>Range of GSI measurements for immature (maturity code = 0) and mature (1) males</td>
<td>77</td>
</tr>
<tr>
<td>40</td>
<td>The relationship between oviducal gland width and total length for females collected North of Cape Mendocino</td>
<td>79</td>
</tr>
<tr>
<td>41</td>
<td>The relationship between oviducal gland width and total length for females collected South of Cape Mendocino</td>
<td>79</td>
</tr>
<tr>
<td>42</td>
<td>Relationship between uterus width and total length for all immature and mature females collected North of Cape Mendocino</td>
<td>81</td>
</tr>
<tr>
<td>43</td>
<td>Relationship between uterus width and total length for all immature and mature females collected South of Cape Mendocino</td>
<td>81</td>
</tr>
<tr>
<td>44</td>
<td>Relationship between maximum ova diameter (MOD) and total length for immature and mature females collected North of Cape Mendocino</td>
<td>82</td>
</tr>
<tr>
<td>45</td>
<td>Relationship between maximum ova diameter (MOD) and total length for immature and mature females collected South of Cape Mendocino</td>
<td>83</td>
</tr>
<tr>
<td>46</td>
<td>Relationship between age and ovary weight for females collected during the survey</td>
<td>84</td>
</tr>
<tr>
<td>47</td>
<td>Plot of immature and mature female GSI versus total length</td>
<td>84</td>
</tr>
<tr>
<td>48</td>
<td>Hepatosomatic index of immature and mature females collected during the 2003 survey plotted by total length</td>
<td>85</td>
</tr>
<tr>
<td>49</td>
<td>Uterus width index of all mature females collected North of Cape Mendocino graphed by date of catch</td>
<td>86</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>50.</td>
<td>Hepatosomatic index of mature females by date (collected during 2003 survey)</td>
<td>87</td>
</tr>
<tr>
<td>51.</td>
<td>Maximum ova diameter of mature females and the monthly average plotted by date of capture (2003-2004)</td>
<td>87</td>
</tr>
<tr>
<td>52.</td>
<td>Gonadosomatic index ratios of mature females by date of catch in summer of 2003</td>
<td>88</td>
</tr>
<tr>
<td>53.</td>
<td>Number of egg cases found in the uteri of females found North of Cape Mendocino according to date in 2003 and 2004</td>
<td>88</td>
</tr>
<tr>
<td>54.</td>
<td>Proportion mature for northern male <em>R. rhina</em>, by age and length. The fitted curve is also shown</td>
<td>90</td>
</tr>
<tr>
<td>55.</td>
<td>Proportion mature for southern male <em>R. rhina</em>, by age and length. The fitted curve is also shown</td>
<td>91</td>
</tr>
<tr>
<td>56.</td>
<td>Proportion mature for northern female <em>R. rhina</em>, by age and length. The fitted curve is also shown</td>
<td>92</td>
</tr>
<tr>
<td>57.</td>
<td>Proportion mature for southern female <em>R. rhina</em>, by age and length. The fitted curve is also shown</td>
<td>93</td>
</tr>
<tr>
<td>58.</td>
<td>Diagram of a bottom trawl net with footrope gear indicated</td>
<td>105</td>
</tr>
<tr>
<td>59.</td>
<td>Length frequency distribution of male and female <em>R. rhina</em> Oregon commercial landing samples (1995-2005) caught by small footrope bottom trawl gear in the U.S. Vancouver INPFC management area</td>
<td>106</td>
</tr>
<tr>
<td>60.</td>
<td>Length frequency distribution of male and female <em>R. rhina</em> Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the U.S. Vancouver INPFC management area</td>
<td>106</td>
</tr>
<tr>
<td>61.</td>
<td>Length frequency distribution for male and female <em>R. rhina</em> Oregon commercial landing samples (1995-2005) caught by small footrope bottom trawl gear in the Columbia INPFC management area</td>
<td>107</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>62.</td>
<td>Length frequency distribution for male and female <em>R. rhina</em> Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the Columbia INPFC management area.</td>
<td>107</td>
</tr>
<tr>
<td>64.</td>
<td>Length frequency distribution for male and female <em>R. rhina</em> Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the Eureka INPFC management area.</td>
<td>108</td>
</tr>
<tr>
<td>65.</td>
<td>PacFIN landings data (metric tons) for the category “unspecified skates” from 1980 to 2004. The PacFIN database is composed of information from fish landing receipts which are completed by the processing plants and collected by the state fish and wildlife agencies.</td>
<td>110</td>
</tr>
<tr>
<td>66.</td>
<td>Average revenue per pound for skate landings on the west coast (1981-2005).</td>
<td>111</td>
</tr>
<tr>
<td>67.</td>
<td>Total annual skate landings by gear type for the U.S. Vancouver INPFC area.</td>
<td>113</td>
</tr>
<tr>
<td>68.</td>
<td>Total annual skate landings by gear type for the Columbia INPFC area.</td>
<td>114</td>
</tr>
<tr>
<td>69.</td>
<td>Total annual skate landings by gear type for the Eureka INPFC area.</td>
<td>115</td>
</tr>
<tr>
<td>70.</td>
<td>Total annual skate landings by gear type for the Monterey INPFC area.</td>
<td>116</td>
</tr>
<tr>
<td>71.</td>
<td>Total annual skate landings by gear type for the Conception INPFC area.</td>
<td>117</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>72.</td>
<td>A length-frequency distribution for male, female and unidentified <em>R. rhina</em> collected north of Cape Mendocino for the 2001 NOAA Fisheries triennial west coast groundfish bottom trawl survey. Page 121</td>
<td></td>
</tr>
<tr>
<td>73.</td>
<td>A length-frequency distribution for male, female and unidentified <em>R. rhina</em> collected south of Cape Mendocino for the 2001 NOAA Fisheries triennial west coast groundfish bottom trawl survey. Page 121</td>
<td></td>
</tr>
<tr>
<td>74.</td>
<td>A length-frequency distribution for male, female and unidentified <em>R. rhina</em> collected north of Cape Mendocino for the 2004 NOAA Fisheries triennial west coast groundfish bottom trawl survey. Page 122</td>
<td></td>
</tr>
<tr>
<td>75.</td>
<td>A length-frequency distribution for male, female and unidentified <em>R. rhina</em> collected south of Cape Mendocino for the 2004 NOAA Fisheries triennial west coast groundfish bottom trawl survey. Page 122</td>
<td></td>
</tr>
<tr>
<td>76.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC U.S. Vancouver management region (47°30'00&quot; N latitude to ~ 48°30'N). Depth range 55-183 meters. Page 125</td>
<td></td>
</tr>
<tr>
<td>77.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC U.S. Vancouver management region (47°30'00&quot; N latitude to ~ 48°30'N). Depth range 184-366 meters. Page 125</td>
<td></td>
</tr>
<tr>
<td>78.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Columbia management region (43°00&quot; N latitude to ~ 47°30'N). Depth range 55-183 meters. Page 126</td>
<td></td>
</tr>
<tr>
<td>79.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Columbia management region (43°00&quot; N latitude to ~ 47°30'N). Depth range 184-366 meters. Page 126</td>
<td></td>
</tr>
<tr>
<td>80.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Eureka management region (40°30’N latitude to ~ 43°00’N). Depth range 55-183 meters. Page 127</td>
<td></td>
</tr>
<tr>
<td>81.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Eureka management region (40°30’N latitude to ~ 43°00’N). Depth range 184-366 meters. Page 127</td>
<td></td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>82.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Monterey management region (36°00' N latitude to ~40°30'N). Depth range 55-183 meters.</td>
<td>128</td>
</tr>
<tr>
<td>83.</td>
<td>Biomass estimates for <em>Raja rhina</em> from West Coast triennial survey data for the INPFC Monterey management region (36°00' N latitude to ~40°30'N). Depth range 184-366 meters.</td>
<td>128</td>
</tr>
<tr>
<td>84.</td>
<td>Catch curve data for male and female <em>Raja rhina</em> caught on the 2003 West Coast Groundfish survey, North of Mendocino.</td>
<td>131</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>61</td>
<td></td>
</tr>
</tbody>
</table>

1. Von Bertalanffy growth parameters for *Raja rhina* in Monterey Bay (from Zeiner and Wolf 1993)
2. Number of centra sections stained for each combination of solution strength and immersion period
4. Summary of all depths sampled during the 2003 Groundfish survey for INPFC region, depths where *Raja rhina* occurred, and depths of occurrence for all *Raja rhina* included in the survey sample for this study
5. A comparison of precision statistics calculated by comparing the age estimates of the reader against the estimates of the tester
6. A comparison of von Bertalanffy growth parameters calculated with data from the second intercomparison study
7. The final growth parameters for each group which were estimated by fitting the 2-parameter VBGF (using $L_0=14.5$) to age and length data
8. Calculated von Bertalanffy growth parameters and maximum age found for four species belonging to the family Rajidae
Age, Growth and Maturity of the Longnose Skate (*Raja rhina*) for the U.S. West Coast and Sensitivity to Fishing Impacts
CHAPTER 1. GENERAL INTRODUCTION

Long-lived marine animals generally have slow growth and late maturity. In addition, many long-lived species have other k-selected life history traits such as low fecundity or inconsistent recruitment. Long-lived marine animals tend to be particularly vulnerable to rapid increases in mortalities after which recovery may take decades (Musick 1999; Heppell and Heppell, 2005). Groups which seem to be particularly vulnerable to increases in mortality include most elasmobranchs, most chondrichthians, some teleosts, and the cheloniid sea turtles. The greatest threats to long-lived marine animals come from mixed species fisheries in which long-lived species are taken incidentally. Such fisheries may reduce long-lived species to critical levels while the targeted and more productive species sustain catches. In addition, the catch levels and mortalities of the target species are monitored in these fisheries, whereas the effects of such fisheries on non-targeted, long-lived species are not monitored or have not been until recently.

The class Chondrichthyes includes all cartilaginous fishes, sharks, skates, rays (elasmobranchs) and chimaeras. Recently the depletion of many traditionally targeted fish species by commercial fishing practices has led to a more directed fishing effort on previously non-targeted species, including elasmobranchs (FAO 1998). Additionally elasmobranch catches in incidental fisheries have been occurring for the last 40 years or more. The increase in elasmobranch fishing mortality is of great concern because like other long-lived species they have life history characteristics which make them more vulnerable to overfishing than traditionally
targeted species (Dulvy et al. 2000; Holden 1974; Holts 1988). Even more concerning is the fact that the research and conservation of these species has been a low priority in the past, a result of the lower economic value of shark and ray products (Bonfil 1994). Consequently the populations of many elasmobranch species around the world have now been depleted or are currently being overexploited.

In the last forty years, at least two known skate species have been locally depleted due to fisheries practices. The common skate, *Raja batis*, was once abundant in the early 20th century, and was reportedly fished year-round on all fishing grounds of the Irish Sea. Now it is locally extinct. Research trawl data for the Irish Sea show that not a single common skate was taken during surveys conducted in the 1970’s (Brander, 1981). The barndoor skate, *Raja laevis*, historically ranged from Georges Bank (Northern New England coast) to the Grand Banks of Newfoundland, and was once the second most abundant skate species off St. Pierre Bank, Newfoundland. Casey and Myers (1998) estimate that *R. laevis* biomass has been decreasing in all portions of its range at a rate of 27% per year since the 1960’s. It is likely that the regional depletion of these two skate species has occurred due to a combination of similar factors. Skates, like other elasmobranchs, tend to exhibit more k-selected life history traits than those of bony fishes which have historically been targeted in trawl fisheries. When k-selected species experience rapid increases in fishing mortality, the recruitment rate, or the number of young which survive to maturity, can be drastically reduced (Holts, 1988). Additionally, the practice of
bottom trawling, a method of harvesting fisheries resources, has been commonly used within the range of these skate species for at least 100 years. Due to their large hatching size, both species are susceptible to this fishing gear at quite a young age, possibly within their first year of life (Casey and Meyers, 1998; Brander 1981). Based on similar reasons for decline of these two species, it seems quite plausible that skate stocks impacted by trawl fisheries in regions outside the Irish Sea and the Northwest Atlantic may also face the risk of local depletion, either currently or in the near future.

In order to prevent the local depletion of skates on the West Coast, it is essential that basic life history data and fisheries data be collected for those species subjected to the heaviest fishing impacts. *Raja rhina* is one of four skate species commonly caught in West Coast groundfish trawls as bycatch, along with sandpaper skate *Raja kincadii*, California skate *Raja inornata* (especially off California, big skate *Raja binoculata*, and roughtail (a.k.a. black) skate *Bathyraja trachura*, (Allen Cramer, Coordinator for NOAA Fisheries Observer Program in Oregon, Pers. Comm.). Additionally *Raja rhina* is the most common skate species landed for seafood processing in Oregon, along with the occasional big skate or California skate. There exists a small amount of life history information for *Raja rhina* at present. There is also a paucity of species-specific fisheries data collected for any skate species on the West Coast. Therefore, the goal of this research is to provide the basic information needed for a future *R. rhina* stock assessment in order to better
understand the current status of this potentially sensitive species and how it may be affected by fishing impacts.

Objectives

The three primary objectives were to:

1) Determine accurate age and growth parameters for *Raja rhina*, over a broad geographic area, by validating periodic growth band formation, and providing estimates of between and within-reader age bias for this particular species.

2) Assess the reproductive status of male and female *Raja rhina* along the U.S. West Coast by (a) calculating length and age at maturity (using results from the age and growth study) for each sex, (b) testing for latitudinal differences in the onset of maturity and (c) checking for indications of seasonality in the reproductive cycle.

3) Assess current fisheries data pertaining to *Raja rhina*, by (a) evaluating biomass trends, (b) estimating the total instantaneous mortality rate, and (c) providing information about the past and present market for skates in the seafood industry.
Age and growth of the longnose skate, *Raja rhina*, off the coast of Washington, Oregon and California

Josie Thompson

Not yet submitted
CHAPTER 2. AGE AND GROWTH

ABSTRACT

Age and growth of the longnose skate, *Raja rhina*, from the Washington, Oregon and California coast was estimated by counting bands on vertebral centra thin-sections from 423 individuals (data from an additional 138 were discarded due to poor clarity). The two parameter von Bertalanffy growth function (using length at hatch = 14.5 cm) was chosen to describe the relationship between age and growth as it provided a good fit to the data and gave the most reasonable estimates for the growth parameters $L_{\infty}$ and $k$. Using an analysis of residual sum of squares (ARSS) no significant difference was found between male and female growth ($f$-stat = 0.4740; d.f. 401; $p = 0.701$), though a significant difference was found between northern and southern latitudinal regions ($f$-stat = 21.4575; d.f. 251; $p = 2.095 \times 10^{-12}$). Skates collected north of Cape Mendocino ($L(t) - 14.5 = 170.03(1 - \exp(-0.0586 \times t))$) were found to grow slower and reach a greater asymptotic length than skates collected south of Cape Mendocino ($L(t) - 14.5 = 138.26(1 - \exp(-0.0656 \times t))$). Inaccurate growth parameters may have been estimated for the southern region samples due to a lack of large-sized individuals. The oldest female skate from the North was aged at 22 and the oldest female skate from the South was aged at 16 years. The oldest male skate from the North was aged at 20 and the oldest male skate from the South was aged at 15 years. Age inter-comparison studies with two different readers resulted in low precision between readers (APE values = 8.31 and 7.87, ACV = 13.75 and 13.51). When compared to the author's counts, reader 1's counts had a more
consistent negative bias (39.8%) than positive bias (17.35%), and reader 2’s counts had a more consistent positive bias (49.38%) than negative bias (18.52%). On average the author’s counts fell between the counts of the two additional readers. Marginal increment analysis and centrum edge classification results lent support to the hypothesis that opaque bands are formed during the winter months.

INTRODUCTION

Life History

The longnose skate, *Raja rhina* (family: Rajidae), occurs from the southeastern Bering Sea to Cedros Islands, Baja California and has also been found in the Gulf of California (Mecklenburg et al., 2002). Their depth range extends from the nearshore (~25 meters) to 1000 meters (Ebert, 2003). Data from NOAA Fisheries West Coast groundfish survey indicate they are most frequently caught at depths of 100-150 m. A recent tagging study conducted off British Columbia found that *Raja rhina* are capable of making fairly large latitudinal movements (McFarlane, Pers. Comm.). Habitat preferences include mud-cobble bottom near boulders, rock ledges, and areas located under vertical relief structure (Ebert, 2003). As with all skate species, *R. rhina* has internal fertilization, is oviparous, and deposits tough, leathery egg cases on the sea bottom, inside of which the young develop. Egg cases are 8-12 cm in length and hold one individual per case (Roedel and Ripley, 1950). The young are fully developed when they emerge from the egg case although they do have a yolk-sac at emergence (Talley, 1983). Total length at birth ranges from
12-17 cm (Ebert, 2003). Three 2-month-old *R. rhina* collected from the Oregon Coast Aquarium for this study had total lengths which ranged between 15 and 19 cm.

Some previous research on the age and growth of *R. rhina* has been conducted. Zeiner and Wolf (1993) examined the age, growth and maturity of *R. rhina* in the Monterey Bay, California area and found a maximum age of 13 years and a maximum length of 132 cm. The age and length data from the skates collected by Zeiner and Wolf (1993) were fitted to the von Bertalanffy growth equation (Table 1). Zeiner and Wolf collected a total of 132 individuals, only two of which were greater than 100 cm in total length. Since the reported maximum length for *R. rhina* (before this study) was 137 cm (Eschmeyer et al. 1983), it is unlikely that growth parameters calculated in the Zeiner and Wolf study are accurate. Additionally, variation in age and growth has been reported among con-specific elasmobranch populations (Saunders and McFarlane 1993; Parsons 1993b; Wintner and Cliff 1995). Therefore it is important to assess whether age and growth parameters differ between *R. rhina* found off of southern California and those found off of Washington and Oregon, primarily for appropriate management of the species.

Table 1. Von Bertalanffy growth parameters for *Raja rhina* in Monterey Bay (from Zeiner and Wolf, 1993).

<table>
<thead>
<tr>
<th></th>
<th>Linf (mm)</th>
<th>k</th>
<th>t(0)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>967 (100 SE)</td>
<td>0.25 (0.10 SE)</td>
<td>0.73 (1.1 SE)</td>
<td>664</td>
</tr>
<tr>
<td>Female</td>
<td>1069 (131 SE)</td>
<td>0.16 (0.05 SE)</td>
<td>-0.3 (0.08 SE)</td>
<td>68</td>
</tr>
<tr>
<td>Both</td>
<td>1047 (1047 SE)</td>
<td>0.17 (0.05 SE)</td>
<td>-0.16 (0.62 SE)</td>
<td>132</td>
</tr>
</tbody>
</table>
Age Determination, Precision and Accuracy

The biggest challenge to any age and growth study is making accurate age determinations. Proficient age reading requires a great amount of practice and training, (for certain species more than others). It is also necessary to make sure that the methods used to make age determinations are precise and accurate. Structures which are commonly used to age fish include otoliths (ear bones), scales, spines, and vertebrae. Since elasmobranchs do not have otoliths, the most common structure used to age cartilaginous species is the vertebral centrum (Cailliet and Goldman 2004). These structures must be prepared and then viewed under the microscope with transmitted or reflected light. It is often assumed that one pair of light and dark bands represents one year of a fish’s growth, (referred to as an annulus or growth ring), though this is not always the case.

Beamish and McFarlane (1983) and Cailliet (1990) have emphasized the importance of age validation and verification. Cailliet (1990) describes validation as “proving the accuracy of age estimates by comparison with a determinate method”, and verification as “confirming an age estimate by comparison with other indeterminate methods”. A determinate method is one which represents the true age of an individual, and therefore comparisons against it prove whether or not the reader’s estimates are accurate. Comparison with an indeterminate ageing method merely confirms the repeatability of age estimates (or precision), but does not confirm their accuracy.
Age verification may involve comparing estimates (for the same sample) between age readers or estimates using different methods or age structures.

Evaluating the precision between age readers (or methods) was once commonly calculated by average percent agreement (APA), where percent agreement is calculated as: \( PA = \frac{\text{No. agreed}}{\text{No. read}} \times 100 \). However this statistic does not provide a useful means of comparison between species and ages (Beamish and Fournier 1981; Campana 2001). Therefore the most frequently used precision statistic today is average percent error (APE) which was introduced by Beamish and Fournier (1981) and modified by Chang (1982) as the coefficient of variance (CV).

The average percent error is calculated for each fish as

\[
100\% \times \frac{1}{R} \sum_{i=1}^{R} \left| \frac{X_{ij} - X_j}{X_j} \right|
\]

Where \( R \) = number of times each fish was aged, \( X_{ij} \) the \( i \)th age determination for the \( j \)th fish, and \( X_j \) = the average calculated age for the \( j \)th fish among all determinations made for the individual. The average APE can then be calculated for each age or length class, as well as the entire set of inter-comparison data. Chang’s (1982) modification of APE incorporates standard deviation into the equation rather than absolute deviation from the mean age (Campana et al. 1995). The average coefficient of variation, ACV (also refereed to as V), is calculated for each fish as

\[
100\% \times \sqrt{\frac{\sum_{i=1}^{R} (X_{ij} - X_j)^2}{R-1 X_j}}
\]
Hoenig et al. (1995) suggest that APE and CV statistics, when averaged over many fish, are not always comparable. These statistics can differ if the sampling design changes (i.e. number of times each fish is read) or if readers change (Hoenig et al. 1995). However, APE and CV values can be useful for comparing precision between two readers for different age classes. Hoenig et al. (1995) also suggests that percent agreement can be a very useful and intuitive statistic for initial analysis of inter-comparison data.

Calculation of percentage bias, or simply the difference between two readers, is also a useful means of comparison which helps to detect systematic errors between readers (Campana et al., 1995, Kimura and Lyons, 1991). Bias is a critical means of analyzing inter-comparison data and should be tested for prior to any other tests of precision (Campana et al. 1995; Evans and Hoenig 1988). Percent bias is not a calculation of agreement, but rather a calculation of how often one reader is ageing higher or lower than the other. It is useful to calculate overall percent bias as well as percent bias per age group. Campana et al. (1995) mention that bias patterns can be most effectively detected with the eye, and a simple age bias plot. Using all methods of precision analysis is the best approach as this allows one to view the data in different ways and make judgements about its usefulness.

Complete validation, or absolute validation for every age, is the supreme goal of every ageing study. Bomb carbon dating is the most recent technique used for complete validation in elasmobranch (Cailliet and Goldman 2004). When the atomic bomb testing took place in the 1950's and 1960's, bomb radiocarbon ($^{14}$C) moved
from the atmosphere to the ocean, and was incorporated into marine carbonates, including fish hard parts (Druffel and Linick 1978) This method measures the radiocarbon (\(^{14}\text{C}\)) in fish hard parts, and compares them to published radiocarbon chronometers. This method can be used to validate annulus formation as well as the absolute age of a fish. However fish must be born between the years 1955 to 1970, and measurement of \(^{14}\text{C}\) is costly (Cailliet and Goldman 2004). Complete validation may also be attained via captive rearing, though it must be conducted for the entire life span of the species. Unfortunately captivity could possibly influence growth as well as growth band formation (Cailliet and Goldman 2004).

Two common methods used for validating the temporal periodicity of ring formation are oxytetracycline (OTC) marking (Cailliet 1990; DeVries and Frie 1996; Campana 2001; Smith et al. 2003) and relative marginal increment (RMI) analysis. OTC marking involves injecting the antibiotic into live fish, letting them roam at liberty for a certain period of time, and then recapturing the marked fish. When injected, the tetracycline will immediately bind to the calcifying age structures, and therefore, a direct comparison can be made between growth band deposition and time at liberty. These methods can only provide complete validation if they are conducted for every age class, and there was additional validation of the first growth ring. For RMI calculation, the width of the last forming growth increment is divided by the width of the last fully formed annulus (Natanson et al. 1995; Wintener et al. 2002; Goldman 2002). The RMI values are plotted against month of capture to determine the amount of time required for growth of the last increment. Classification of the
centrum edge as opaque or translucent is a similar means of validating the temporal periodicity of ring formation; however, appearance of the centrum edge is often difficult to determine, and therefore should not be chosen as the only method for validation.

Validation of the first growth ring is the most critical component for complete validation (Beamish and McFarlane 1983; Cailliet 1990; Campana 2001). Age reading is commonly conducted under a second assumption: that the first annulus is deposited during the first year of growth. While this is the case for most species, Natanson and Cailliet (1990) discovered that the Pacific angel shark (*Squatina californica*) deposit six to seven growth bands on their vertebral centra before birth. However, the Pacific angel shark is also ovoviviparous, with a gestation period of 9 months.

Zeiner and Wolf (1993) attempted to validate the periodicity of longnose skate growth band formation using centrum edge analysis. This method involves categorizing the edge of the age structure as light or dark, and plotting these results by month. They did not find strong evidence for seasonal band deposition, or annual deposition of a pair of light and dark bands, on the vertebral centra of *Raja rhina*.

However, most of their samples were captured during only one season of the year instead of being evenly distributed throughout the year. They were able to show that there was a significant linear relationship between total length (mm) and centrum diameter (mm) for the longnose skate, indicating that age structure growth is correlated to body growth.
In Cailliet's (1990) review of age validation for elasmobranchs, all species for which no banding pattern could be detected belonged to primitive families or were species that occur in deep waters. He showed that age validation attempts have been made for six species of Rajidae, and all have indicated that the growth zone formation for these species follows the general pattern: an annual pair of opaque and translucent bands (Cailliet, 1990). This suggests that validation of the periodicity of growth bands should be possible for *R. rhina* if monthly samples are collected throughout the year.

**Objective 1**

The objectives of this study are to (1) validate periodic growth band formation, (2) provide some estimates of between and within-reader age bias for this particular species, and (3) to accurately determine age and growth parameters for *R. rhina*, over a broad geographic area.

**MATERIALS AND METHODS**

**Sampling Design and Data Collection**

Skates were collected during the 2003 NOAA Fisheries West Coast groundfish survey in order to make comparisons between latitudinal regions possible. This survey, designed to cover the Pacific coast from 55-1280 meters, samples in a stratified random method by randomly selecting sites from a pre-determined sampling grid. Samples were collected between July 10th and August 15th from Coos Bay,
Oregon to the US/Mexico border, and between August 30\textsuperscript{th} and September 15\textsuperscript{th} from Cape Flattery, Washington to Astoria, Oregon.

For each survey sample collected the following information was recorded: date of catch, haul location and depth, sea surface temperature, total length from snout tip to tail tip (0.1 cm), disc width from wing tip to wing tip (0.1 cm), total weight (.01 kg), and sex. All weights recorded aboard the survey were measured using an electric balance. A section of the backbone (vertebrae #1-25, posterior to scapular origin of vertebral column), containing the vertebral centra, was removed from each skate for use in age determination. These structures were tagged with an identifying sample number and frozen in individual bags. Ageing structures and additional data were not collected for every longnose skate caught while aboard the survey due to time limitations.

In addition, skates were collected on a near-monthly basis for one year from commercial groundfish trawl landings made at the Pacific Shrimp seafood processing plant in Newport, Oregon. These samples were primarily collected for later RMI analysis, with the assumption that all samples landed at Pacific Shrimp came from catches made off the coast of Oregon. This assumption was validated by checking fish ticket and logbook data for each of the landings sampled. As changes in environmental conditions including food availability, temperature, and photoperiod may affect the timing of seasonal band deposition on the vertebral centra, it is important that all samples used for the validation analysis were collected from the same general region (Jones and Geen 1977; Mugiya et al. 1981; Brothers 1983). For
validation of the birth indicator, three 2 month-old *Raja rhina* from the Oregon Coast Aquarium were obtained and their vertebral centra examined.

For all monthly Oregon port samples the following information was recorded: boat name, landing date, total length (0.1 cm), disc width (0.1 cm), total weight, and sex. As with samples collected from the West Coast groundfish survey, a section of the backbone (vertebrae #’s 1-25) was collected for ageing purposes. Individual weights were measured using a Chantillon IN-series hand scale.

**Vertebral Centra Preparation Method**

Vertebral centra were prepared as follows: Vertebrae were defrosted and for each sample the 17th -20th vertebrae were selected and separated. The arches, skin tissue and some cartilage were removed from the vertebral centra with a scalpel. Extra skin tissue and cartilage was removed by cleaning the centra in hot water (not boiling), and soaking in 5% sodium hypochlorite (bleach) for several minutes (Carlson et al., 1999). The centra were then dried overnight and stored dry at room temperature in glass vials.

To prepare vertebrae for thin sectioning, one centrum from each specimen was centered on a small square (1 3/8” x 7/8”) of thick paper (one side waxed), mounted using clear-lite surface curing resin with MEKP liquid catalyst (TAP Plastics, Inc., Dublin, CA), and left to dry overnight. Using a Buehler isomet saw and two 4” wafering blades with a 3 μm separator (made of overhead transparency sheets), a 3μm section was made through the focus (widest diameter) of each centrum.
Before a final preparation method was chosen, several methods to enhance the visibility of the growth bands were tested, including the cobalt nitrate and ammonium sulfide treatment used by Hoenig and Brown (1988) with whole centra (not thin-sectioned), the alizarin red technique used by La Marca (1966) with thin-sections, and the crystal violet technique used by Gallagher and Nolan (1999) with thin-sections. These were also compared to unstained thin-sectioned samples. The cobalt nitrate and ammonium sulfide technique produced some banding patterns on the exterior of whole centra, although the pattern became too crowded near the edges (Figure 1). Crystal violet solution enhanced the banding pattern best, although at certain times the dye also seemed to conceal certain band patterns, especially if overdyeing occurred.

Figure 1. Photo of whole centra stained by the methods of Hoenig and Brown (1988).
Tests were then conducted to optimize crystal violet solution concentration, and section immersion time. Centra sections of similar size were prepared using different combination of solution strength (0.5%, 1% and 5%) and immersion period (30, 40, 50 and 60 minutes) (Table 2). It was found that a longer immersion time in a more dilute solution helped to increase band resolution.

Table 2. Number of centra sections stained for each combination of solution strength and immersion period.

<table>
<thead>
<tr>
<th>Immersion time (minutes)</th>
<th>Solution concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.50%</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
</tr>
</tbody>
</table>

Ultimately all vertebral centrum sections (for which age determinations were made for this study) were soaked in 0.5% crystal violet solution for 45-60 minutes. The largest sections were soaked for 60 minutes, and the smaller sections were soaked for 45 minutes. Sections were mounted (side furthest from the focus, facing up) on half-frosted microscope slides with Cytoseal (Richard-Allan Scientific, Kalamazoo, MI 49007). A process of grinding and polishing using 1200 and 1500 grit sandpaper with water, and a polishing pad with water and Alumina B Gamma Micropolish (#3-05, Buehler Inc., Lake Bluff, IL), was repeated until sections attained a thickness of ~ 1 μm.
Age Reading Methods and Criteria

All of reader 1’s age determinations were made using a Leica MZ 9s microscope (Bartels and Stout, Inc. Bellevue, WA 98009). Reader 2 used an Olympus BH microscope, and reader 3 made age determinations via video microscope using an Accuscope 3001 with a Hitachi KP-D20A color camera. As described by Chilton and Beamish (1982) an “annulus” or growth increment was defined as one pair of dark and light bands (Figure 2). The number of growth increments on each centrum was counted from the focus to the last completed annulus along the axis with the clearest growth band pattern. The three remaining axes were used to verify band occurrence on the main axis (Gallagher and Nolan, 1999) (Figure 2). If the edge of the centrum was light, without any hint of a dark band, the last light band would not be included in the count. In addition to age estimation, the following information was also recorded for each age sample read; primary axis used, section clarity rating (1-5, Appendix 1), and remarks. Sections with a clarity rating of 4 or 5 were prepared a second time and, and discarded if the clarity was still poor.

To become familiar with the *R. rhina* vertebral banding pattern one hundred vertebral centra sections were examined multiple times by reader 1. Two training sessions were also conducted with a practiced skate age reader at the Pacific Shark Research Center in Moss Landing, California (reader 2). Though the age reader from Moss Landing was familiar with ageing other skate species, he had not had any experience ageing *Raja rhina*. During these meetings a minimum of 30 centrum sections were viewed by both readers and *Raja rhina* growth band interpretations
were analyzed and discussed. During the second meeting, some sections which had been previously read by both readers were also viewed, in particular, sections for which there was a large band count discrepancy between readers. There was no double-scope available for these training sessions. As a result, the appearance of the banding pattern under the microscope was often illustrated by one of the readers with pencil and paper in order to demonstrate where each count was made.

Figure 2. Definition of an annulus as a pair of one light and one dark band. Also shown, the chosen primary reading axis.

Ageing Precision

Before the final ageing study was conducted, a subsample of 98 centra sections, equally representative of all age classes, were read at least twice by reader 1 and reader 2). This was done in order to assess reader 1’s precision and inter-reader variability. The precision and bias within and between readers was assessed by
calculating the following for each age class and for the entire sample: average percent agreement (APA), average percent error (APE) (Beamish and Fournier 1981), average coefficient of variance (ACV) (Chang 1982), and percent bias (Campana et al. 1995).

Since the first double read resulted in very high inter-reader variability and considerable bias between readers, readers 1 and 2 met again to review their ageing techniques, and established ageing procedure criteria (Appendix 2). A new sub-sample of 100 centra sections, almost equally representative of all age classes, was read again by both to reassess within and between reader variability. Two reads were conducted for each sample, as in the first study, but in the second double read both readers viewed sections a third time if agreement on age was not reached on the first two reads. The two readers then decided upon a final age determination to be used for between-reader comparisons. Previous estimates for each sample structure were taken into consideration when choosing a final age.

Since the second study still resulted in considerable bias between readers, a third opinion was requested. A new reader (reader 3) was chosen to make age estimates on the same set of sections used in the second inter-reader comparison study. This reader was a graduate student working with elasmobranch life history researchers at the NOAA Fisheries Northeast Fisheries Science Center in Narragansett, Rhode Island. There was only enough time for reader 3 to make one set of age estimates for comparison with the author's age estimates. The same statistics were calculated for all inter-reader comparisons.
All remaining age structures not included in the double read samples were read two or three (if agreement between the first two determinations was not reached) times by reader 1 in order to arrive at a final determination for each. Most structures with a clarity rating of 4 or 5 were prepared a second time using a new vertebral centrum. Optimally, all structures with a clarity rating of 4 or 5 should be discarded. A few samples with a clarity rating of 4 were kept in order to augment the small sample size for males collected south of Cape Mendocino.

**Age Validation**

Validation for all ages was not attempted in this study. Relative marginal increment (RMI) analysis and centrum edge classification was used to validate the assumption that one dark and one light band represents one year of growth. Image Pro Plus (Version 5.0) software was used to measure the last growing \( (I_U) \) and last fully formed increment \( (I_C) \) of all vertebral centra sections (monthly samples only) with distinctive growth bands at the end of one or more axes. Increments were measured between the far edges of each light band. The marginal increment ratio \( (MIR = I_U / I_C) \) was calculated which corrects for differences in band width between small and large fish (Natanson et al., 1995). Marginal increment ratio results were plotted against month to validate periodic trends in band formation.
Morphometrics

Disc width was regressed against total length to show whether a strong relationship existed between these two common measurements of growth for skate and ray species. A linear regression was also fit to the log transformed body weight data and the log transformed disc width data for both sexes. These relationships will be useful for converting length (or width) data to weight data, and may be helpful for estimating fishing mortality. Oftentimes fisheries data from the past may include individual length data but not individual weight data.

An ANOVA F-test was used to test for a statistically significant difference in the relationship of disc width to total length as well as disc width to body weight between males and females, and between northern and southern regions. Cape Mendocino was chosen as the North/South boundary line for all comparisons between high and low latitudes in this study as it is commonly used by the Pacific Fisheries Management Council (PFMC) for management decisions affecting marine fish species.

Growth

Several different growth curves were fit to the age and length data for males and females, and for northern and southern latitudinal regions using Sigma Plot software. These models included the von Bertalanffy growth function:

\[ L_t = L_{\infty} \times \{1 - \exp[-k*(t - t_0)]\} \]
Where $L_t$ = length at age $t$, $L_{\text{inf}}$ = Asymptotic length, $k$ = instantaneous growth rate, $t$ = age, and $t_0$ = theoretical time at length 0.

The logistic growth equation:

$$Y_t = \frac{K}{1 + \left(\frac{K - Y_0}{Y_0}\right)[\exp(-rt)]}$$

Where $Y_t$ = length at age $t$, $K$ = Asymptotic length, $r$ = logistic growth coefficient, and $Y_0$ = size at birth.

Also, since $t_0$ is proposed to be an estimation of time when size is 0, which assumes that embryonic growth is governed by the same growth parameters as post-hatch growth, a more simplified version of the von Bertalanffy growth curve was also fit to the data, using $L_0$, or length at hatch, as the third parameter (Fabens 1965):

$$L_t - L_0 = L_{\text{inf}}^* [1 - \exp(-k^*t)]$$

Where $L_0$ is defined as 14.5 cm, the average known length at hatch for *R. Rhina*.

An analysis of the residual sum of squares (ARSS) was used to statistically compare growth functions between the sexes and latitudinal regions using the methods of Chen and coworkers (1992).
RESULTS

Data Collection

Between June 17th and September 8th, 2003, a total of 317 *Raja rhina* were collected along the U.S. West Coast while aboard the NOAA Fisheries NWFSC annual groundfish survey: 149 males (19 to 124 cm) and 168 females (18 to 125 cm) (Figure 3). Survey samples were collected along the majority of the U.S. West Coast except between 43°30′00″ N and 46°50′00″ N latitude (Table 3 and Figure 4). Close to the entire known depth range for *Raja rhina* was sampled in each region along the coast. The portion of the depth range which was not sampled in each region ranged between 10 and 60 meters, and included only the most shallow portion of the species depth range (Table 4).

![Figure 3. Number of male and female *Raja rhina* sampled during the 2003 West Coast groundfish survey data collection for each 10 cm total length bin.](image-url)
Table 3. Summary of 2003 groundfish survey sample distribution. The results of this sample have been split among five International Northern Pacific Fisheries Management Council (INPFC) management regions as well as between males and females. See figure X for a map of these regions and Washington, Oregon and California.

<table>
<thead>
<tr>
<th>Region</th>
<th>North Boundary:</th>
<th>South Boundary:</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver</td>
<td>U.S. Canada International boundary</td>
<td>47°30'00&quot; N latitude</td>
<td>28</td>
<td>25</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47°30'00&quot; N latitude</td>
<td></td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Columbia</td>
<td>47°30'00&quot; N latitude</td>
<td>43°00'00&quot; N latitude</td>
<td>6</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>43°00'00&quot; N latitude</td>
<td></td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Eureka</td>
<td>43°00'00&quot; N latitude</td>
<td>40°30'00&quot; N latitude</td>
<td>48</td>
<td>42</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40°30'00&quot; N latitude</td>
<td></td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Monterey</td>
<td>40°30'00&quot; N latitude</td>
<td>36°00'00&quot; N latitude</td>
<td>35</td>
<td>44</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36°00'00&quot; N latitude</td>
<td></td>
<td></td>
<td>79</td>
</tr>
<tr>
<td>Conception</td>
<td>36°00'00&quot; N latitude</td>
<td>U.S. Mexico International Boundary</td>
<td>32</td>
<td>42</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74</td>
</tr>
<tr>
<td>All Regions</td>
<td></td>
<td></td>
<td>149</td>
<td>168</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20-124</td>
<td>18-125</td>
<td>317</td>
</tr>
</tbody>
</table>

---

The table above summarizes the sample distribution for 2003 groundfish surveys. Each region is defined by its northern and southern boundaries, and the sample is further divided between males and females. The total sample size and the size range of the samples are also provided.
Figure 4. A map of the five designated International Northern Pacific Fisheries Council (INPFC) fisheries management regions as defined by latitude (PFMC 1997).
Table 4. Summary of all depths sampled during the 2003 Groundfish survey for each International North Pacific Fisheries Commission (INPFC) region, depths where *Raja rhina* occurred, and depths of occurrence for all *Raja rhina* included in the survey sample for this study.

<table>
<thead>
<tr>
<th>INPFC Region</th>
<th>Depths towed (m)</th>
<th>Depths of occurrence (m)</th>
<th>Depths covered in study sample (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver</td>
<td>65-1155</td>
<td>98-471</td>
<td>111-471</td>
</tr>
<tr>
<td>Columbia</td>
<td>88-1066</td>
<td>88-411</td>
<td>88-411</td>
</tr>
<tr>
<td>Eureka</td>
<td>60-1167</td>
<td>60-492</td>
<td>84-492</td>
</tr>
<tr>
<td>Monterey</td>
<td>36-1201</td>
<td>101-992</td>
<td>101-992</td>
</tr>
<tr>
<td>Conception</td>
<td>34-1078</td>
<td>75-544</td>
<td>123-544</td>
</tr>
</tbody>
</table>

In addition to the survey sample collection, between February 2003 and November 2004, a total of 234 *R. rhina* were collected off the coast of Oregon and landed in the port of Newport, Oregon. The majority of these monthly collections came from commercial landings, though two were provided by research survey catches. The source of the August 2003 sample was a flatfish trawl survey conducted by the Oregon Department of Fish and Wildlife (ODFW) and the June 2004 sample was taken from West Coast Groundfish survey catches. The length of individuals from commercial catch landings alone ranged from 50 to 142 cm. A total of 86 males (31 to 129 cm) and 148 females (19 to 142 cm) (Figure 5) were collected from nine different months of the year. Sample size by month ranged between 17 and 27 individuals (Figure 6).

In order to appropriately conduct a validation study using RMI analysis, it is necessary that all monthly samples which are analyzed for the study be collected from the same general region. A map of general start and finish locations for all but one commercial landing sampled was provided by Oregon Department of Fish and
Wildlife (ODFW) (Figure 7). The sample from April 2004 could not be accounted for in the fish ticket data, though it was still used in the relative marginal increment analysis.

A total of 138 age structures (out of 561) were discarded and not used in the final analyses. Most of these were discarded because of the low clarity rating. Since all sections with low clarity ratings initially were prepared a second time, sections discarded from the study may have been unclear due to physiological factors affecting the deposition of growth bands. A few centra samples were lost in transit between the survey and the lab cleaning process.

Figure 5. Number of male and female *Raja rhina* by 10 cm size class collected from landings made in the port of Newport, Oregon. These landings came from commercial catches and survey catches made off the Oregon Coast between February 2003 and November 2004.
Figure 6. Number of male and female *Raja rhina* collected each month from landings made in the port of Newport, Oregon, between February 2003 to November 2004
Figure 7. Start and finish locations and depths for all commercial catches (excluding one sample) landed and sampled in the port of Newport, Oregon (Oregon coast border in red).
Ageing Precision

A summary table of all age precision statistics allows for a simple comparison between readers and studies (Table 5). Reader 1’s within-reader precision was greater than any between-reader precision, and it improved between studies. Precision and agreement between reader 1 and reader 2 improved between studies; however, the precision between reader 1 and reader 3 was still greater. The degree of bias between reader 1 and reader 2 decreased between studies, though the negative direction remained the same. Conversely, there was a positive direction of bias between reader 1 and reader 3.

Table 5. A comparison of precision statistics calculated by comparing the age estimates of the reader against the estimates of the tester. (APE = average percent error, APA = average percent agreement, ACV = average coefficient of variation, % + bias = positive bias, % - bias = negative bias, w/in 1 = difference between counts = 1 or less, w/in 2 = difference between counts = 2 or less.

<table>
<thead>
<tr>
<th>Study</th>
<th>Tester</th>
<th>Reader</th>
<th>% APE</th>
<th>% APA</th>
<th>% ACV</th>
<th>% + bias</th>
<th>% - bias</th>
<th>w/in 1</th>
<th>w/in 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rdr. 1</td>
<td>Rdr. 1</td>
<td>6.48</td>
<td>38.78</td>
<td>13.70</td>
<td>52.02</td>
<td>9.18</td>
<td>77.6</td>
<td>94.8</td>
</tr>
<tr>
<td></td>
<td>Rdr. 1</td>
<td>Rdr. 2</td>
<td>12.51</td>
<td>28.42</td>
<td>19.38</td>
<td>23.16</td>
<td>48.42</td>
<td>61.1</td>
<td>74.7</td>
</tr>
<tr>
<td>2</td>
<td>Rdr. 1</td>
<td>Rdr. 1</td>
<td>3.46</td>
<td>63.27</td>
<td>5.29</td>
<td>11.22</td>
<td>25.21</td>
<td>91.8</td>
<td>98.0</td>
</tr>
<tr>
<td></td>
<td>Rdr. 1</td>
<td>Rdr. 2</td>
<td>8.51</td>
<td>42.86</td>
<td>13.75</td>
<td>17.35</td>
<td>39.80</td>
<td>88.8</td>
<td>99.0</td>
</tr>
<tr>
<td>2</td>
<td>Rdr. 1</td>
<td>Rdr. 3</td>
<td>7.87</td>
<td>32.10</td>
<td>13.51</td>
<td>49.38</td>
<td>18.52</td>
<td>70.4</td>
<td>91.4</td>
</tr>
</tbody>
</table>

For the initial intra-comparison study, the ageing precision was mediocre and there was also a considerable degree of bias between reader 1’s first and second read (Figure 8). Percent positive bias for the second read was 52.02% whereas percent negative bias was only 9.18%. This bias was in part due to a change in reader 1’s
definition of the age 0 annulus between reads. Before the first read was conducted
the birthmark was defined as the first, very clear light band. But after comparing
larger individuals with known age 0 individuals between reads, the birthmark was re-
defined as the location of the change in the angle of growth, even if a light band was
not apparent at that point. The average percent error (APE) and average percent
agreement (APA) associated with reader 1’s two reads was 6.48% and 38.78%
respectively. Percent agreement per age group decreased as age increased (Figure 9).
The ACV associated with reader 1’s two reads was 13.70 and was relatively similar
over all age classes except age 0 (Figure 10).

Figure 8. Comparison between reader 1’s first and second reads for the initial intra-
comparison study.
Figure 9. Percent agreement results by age class for reader 1's initial intra-comparison study.

Figure 10. Coefficient of variation results by age class for reader 1's initial intra-comparison study.
For the second intra-comparison study, reader 1’s ageing precision between the first and second reads improved considerably over the first study and bias between reads was not quite as strong as it was in the first intra-comparison (Figure 11). Percent positive bias for the second read was 11.22% whereas percent negative bias was 25.21%. Percent agreement did not show a correlation with age, as it was still fairly high for the older age range (Figure 12). The ACV associated with the author’s two reads on the second round was 5.29 and was relatively similar over all age classes except age 0 (Figure 13).

Figure 11. Comparison between reader 1’s first and second read for the second intra-comparison study.
Figure 12. Percent agreement results by age class for reader 1’s second intra-comparison study.

Figure 13. Coefficient of variation results by age class for reader 1’s second intra-comparison study.
For the first inter-comparison study, a comparison of reader 1’s first read and reader 2’s first read showed low precision between readers and a considerable degree of bias (Figure 14). Percent positive bias for reader 2’s estimates compared to reader 1’s estimates was 23.16% whereas percent negative bias was 48.42%, twice as much as the positive bias. Percent agreement by age decreased with increasing age (Figure 15). The ACV between the two readers was high at 19.38, and was relatively similar over all age classes (Figure 16).

Figure 14. Comparison between reader 1’s first read and reader 2’s first read for the initial inter-comparison study.
Figure 15. Percent agreement results by age class for the initial inter-comparison study.

Figure 16. Coefficient of variation results by age class for the initial inter-comparison study.
In the second inter-comparison study between readers 1 and 2, the average percent error was reduced from 12.51% to 8.31%, and average percent agreement increased from 28.42% to 42.86%. There was still a considerable degree of bias between the two readers, though both percent positive and negative bias did decrease between rounds (Figure 17). Percent positive bias for reader 2’s estimates compared to reader 1’s estimates was 17.35% (vs. the previous 23.16%) whereas percent negative bias was 39.8 (vs. previous 48.42%). Percent agreement by age group was generally the same among all age groups (Figure 18). There was only one sample in the 20 year age class. The coefficient of variation per age decreased sharply after age 4 (Figure 19).

Figure 17. Comparison of results for reader 1 and reader 2 for the second inter-comparison study.
Figure 18. Percent agreement for each age class for the second inter-comparison study between reader 1 and reader 2.

Figure 19. Calculated coefficient of variation by age class for the second inter-comparison study between reader 1 and reader 2.
Results from the inter-comparison between reader 1 and reader 3 showed that precision between readers was similar to that found between reader 1 and reader 2. There was still a considerable degree of bias between reader 1 and reader 3; however, in this case reader 3 had a significantly larger percent plus bias, not reader 1 (Figure 20). Percent plus bias for reader 3’s estimates compared to reader 1’s estimates was 49.38% whereas percent minus bias was 18.52%. Percent agreement per age was slightly greater for the younger age groups (Figure 21). However the ACV was higher for younger age groups (Figure 22). The sample size for each age group was not always equal in this study and this should be taken into consideration when making comparisons among age groups (Figure 23).

Figure 20. Inter-comparison results between reader 1 and reader 3.
Figure 21. Percent agreement for each age class between reader 1 and reader 3.

Figure 22. Calculated coefficient of variation by age class for the intercomparison between reader 1 and reader 3.
Figure 23. Number of samples compared for each age class in the intercomparison between reader 1 and reader 3.

To further compare the biases between age readers, the age determinations of all three readers in the second inter-comparison study were used to calculate growth parameters using the 2 parameter von Bertalanffy growth function (where $L(0) = 16$) (Table 6). The growth curve from reader 1’s estimates clearly falls between those of the two other age readers (Figure 24).

Table 6. A comparison of growth parameters calculated by fitting data from the second inter-comparison study to the 2 parameter von Bertalanffy growth function.

<table>
<thead>
<tr>
<th></th>
<th>Reader 1</th>
<th>Reader 2</th>
<th>Reader 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linf</td>
<td>145.4</td>
<td>119.83</td>
<td>174.09</td>
</tr>
<tr>
<td>K</td>
<td>0.0618</td>
<td>0.0865</td>
<td>0.0459</td>
</tr>
</tbody>
</table>
Figure 24. A comparison of von Bertalanffy growth curves using age data from the second inter-comparison study sample.

Age Validation

Although small, all three young-of-the-year longnose skates were thin sectioned. The birth indicator was determined to be at the site where the angle of growth changes significantly after the focus, which corresponded with a small notch in the section (Figure 25).

Growth bands appear as translucent or opaque due to a difference in optical density. This is caused by a seasonal variation in the microstructure of the band being formed. However the physiological processes that cause this seasonal variability are still largely unknown. Relative marginal increment analysis provided little evidence for annual deposition of one pair of translucent and opaque growth bands. There is a
weak but increasing trend in the RMI ratio throughout the year (Figure 26). But overall these data do not provide evidence for a specific time of year at which formation of a new opaque band occurs, as very few marginal increment measurements were less than 40% the width of the last complete increment, and none of these ratios were close to 0. The centrum edge results provided stronger evidence for annual periodicity of growth band formation in *R. rhina* (Figure 27). Since increments were measured between the terminal end of the translucent bands (beginning of opaque bands), these results provide some evidence that opaque bands are formed in the winter and spring.

Figure 25. Photo of a vertebral centra thin-section taken from a 1-year-old *R. rhina* with birth indicator noted (arrow).
Figure 26. Relative marginal increment ratio calculations for *Raja rhina* collected from fisheries landings during 2003 and 2004 and caught off the Oregon coast.

Figure 27. Centrum edge classification by date for *Raja rhina* sections collected from fisheries landings during 2003 and 2004.
Morphometrics

Disc width was strongly correlated with total length, for both males $R^2 = 0.981$ and females, $R^2 = 0.989$ (Figure 28). An analysis of variance F-test gave a non-significant F-value ($F = 0.259, df 2, 549, P = 0.999$) for sex-specific differences in this relationship. Due to the strong relationship between disc width and total length, only total length measurements will be used when describing a relationship to body size. Total length is used more commonly in the literature; therefore, using this measurement makes comparisons with other species simpler. However, disc width is also a common size measurement used for skate and ray species, so the relationship between the two measurements may be useful for future conversions. With disc width and total length both measured in centimeters, the formulae for the curves were as follows:

Male disc width = 0.7108 TL + 0.1902  \quad n = 223

Female disc width = 0.7056 TL − 0.1896  \quad n = 319
Figure 28. The relationship between disc width and total length for all males and females.

Log transformation of disc width and weight data gave a straight line relationship for both sexes (Figure 29). An analysis of variance F-test gave a non-significant F value (F=1.307, df 2, 506; P = 0.65) for a sex-based difference in disc-width-weight relationship. With weight measured in kilograms and DW measured in centimeters, the formulae for the curves were as follows:

Male predicted weight = $10^{(-4.8368 + 3.0219 \times \log_{10} DW)}$ \hspace{1cm} n = 214

Female predicted weight = $10^{(-4.8212 + 3.0145 \times \log_{10} DW)}$ \hspace{1cm} n = 296

An analysis of variance F-test gave a non-significant F-value (F= 0.1012, d.f. 2, 510, P = 0.999) for a difference in the disc width – weight relationship between individuals
caught north and south of Cape Mendocino (40°30'00" N latitude) (Figure 30). The formulae for the curves were as follows:

North predicted weight = 10 \(^{(-5.0194 + 3.1228 \text{ (LOG10 DW)})}\)  \(n = 380\)

South predicted weight = 10 \(^{(-4.7099 + 2.9524 \text{ (LOG10 DW)})}\)  \(n = 210\)

Figure 29. The relationship between log-transformed weight and log-transformed disc width for both sexes.
Growth Curves

North of Cape Mendocino, females ranged between age 0 and 22.5 (16-135 cm). Males in the North ranged between age 0.5 and 20 (27-130 cm). South of Cape Mendocino, females ranged between age 0 and 16 (20-100 cm), and males ranged between age 0 and 15 (19-102 cm).

The 2 parameter von Bertalanffy growth function (VBGF, using $L_0 = 14.5$) was ultimately chosen for modeling the growth of $R. \text{rhina}$ (Table 7). Separate growth curves were fit to the male and female data (Figure 31). Using the analysis of residual sum of squares (ARSS) test, no significant difference in growth was found between the male and female groups ($f$-stat = 0.4740; d.f. 401; $p = 0.701$). Separate growth curves were then fit for the northern and southern regions with sexes combined (Figure 32). Comparison of these curves provided evidence for a
significant difference in growth between regions (f-stat = 32.4356; d.f. 401; p = 8.923 E -19). However, since the dataset used in this latitudinal comparison for the northern region included more larger and older skates (many of which were collected from commercial landings) than the southern region dataset, this first latitudinal comparison may be biased. Therefore, a VBGF was fit to only northern individuals collected on the survey, and this was compared to the VBGF generated for skates from the southern region. This second latitudinal comparison between skates collected on the survey also provided evidence for a statistical difference in growth between northern and southern *R. rhina* (f-stat = 21.4575; d.f. 251; p = 2.095 E-12).

Table 7. The final growth parameters for each group which were estimated by fitting the 2-parameter VBGF (using $L_0=14.5$) to age and length data.

<table>
<thead>
<tr>
<th></th>
<th>$L_{inf}$</th>
<th>K</th>
<th>$T_0$</th>
<th>$R^2$</th>
<th>SEE</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>207.1777</td>
<td>0.0418</td>
<td></td>
<td>0.92287</td>
<td>7.7297</td>
<td>177</td>
</tr>
<tr>
<td>Female</td>
<td>180.9115</td>
<td>0.0513</td>
<td></td>
<td>0.89741</td>
<td>8.9158</td>
<td>227</td>
</tr>
<tr>
<td>Combined</td>
<td>190.698</td>
<td>0.0473</td>
<td></td>
<td>0.90878</td>
<td>8.4104</td>
<td>404</td>
</tr>
<tr>
<td>North</td>
<td>170.0339</td>
<td>0.0586</td>
<td></td>
<td>0.90151</td>
<td>7.9561</td>
<td>271</td>
</tr>
<tr>
<td>South</td>
<td>138.2614</td>
<td>0.0656</td>
<td></td>
<td>0.90062</td>
<td>7.0309</td>
<td>133</td>
</tr>
</tbody>
</table>
Figure 31. The relationship between age and growth for male and female *Raja rhina* with the fitted 2 parameter VBGF.

Figure 32. The relationship between age and growth for *Raja rhina* collected north and south of Cape Mendocino and the fitted 2 parameter and 3 parameter VBGF for each region.
DISCUSSION

Sample Collection

The commercial landing skate length distribution included many more individuals larger than 120 cm total length as compared with the survey length distribution, and no individuals smaller than 50 cm. This could result in a more accurate estimation of life history parameters for the northern region, but could also bias any latitudinal comparisons made.

Many more females were collected from both commercial landings (n = 148) and survey catches (n = 168) than males (n = 86 and 149, respectively). This could be explained by a difference in behavior or life history or it may accurately represent the true sex ratio. However, male and female sample sizes are not much different in the survey collection. More females may be present in the commercial landings due to high grading by the fishermen, as they appear to be selecting the larger-sized skates for processing. Since the maximum observed length for females is larger than males in this study, it is possible that females reach larger sizes and thus are more commonly brought in for processing.

Ageing Precision

The APE and ACV values for the inter-comparison studies show that ageing precision between readers was relatively low. The precision between reader 1 and reader 3 (ACV = 13.51%, APE = 7.87%) was slightly higher than the precision between reader 1 and reader 2 (ACV = 13.75%, APE = 8.31%). These statistics
reflect the relative difficulty in ageing this species, and support evidence that elasmobranch species are often more difficult to age than most osteichthyes (bony fishes). For example, Walmsley-Hart et al. (1999) presented APE values of 10.4% and 11.4% for the yellowspot skate (*Raja wallacei*) and the slime skate (*R. pullopunctata*), respectively. Several age and growth studies for large shark species have calculated APE values above 8% (Sminkey and Musick 1995; Wintner and Dudley 2000; Natanson et al. 2002). Similarly, Francis et al. (2001) calculated ACV values of 18% for the rough skate (*Dipturus nastus*) and 19.8% for the smooth skate (*Dipturus innominatus*).

Thin sections were difficult to age consistently. The low ageing precision between readers can partially be explained by the lack of experience that the readers have had ageing this species. None of the readers have had substantial experience ageing *R. rhina*, though all have had various levels of experience ageing elasmobranch species. Ageing precision is known to improve with experience, and training is necessary for every new species an age reader encounters, as banding patterns in no two species are exactly alike (Kimura and Lyons 1991). This is supported by the fact that precision between reader 1 and reader 2 improved markedly between reads, after the two readers were able to meet a second time and discuss age interpretations. It is highly likely that the low precision was also a result of poor growth band clarity. Only 43 out of 550 sections aged were given a clarity rating of 1 or 2. The three readers in this study believe that clarity of the growth bands could be improved upon with the development of better preparation methods.
The strong degree of ageing bias between readers is of more concern than the lower than average precision. In age comparison studies, if precision is poor and a bias also exists, this not only indicates that there was frequent disagreement between readers, but also that the disagreement was consistently one-sided. This is often caused by a systematic difference in the way the two readers are counting growth bands. Bias can be of greater concern than poor precision because two differing sets of determinations will produce differing growth parameters.

The bias statistics for all inter-comparison studies showed that there was a strong degree of bias between all readers. Although the degree of bias was reduced between the first and second inter-comparison studies between reader 1 and reader 2, reader 2 still maintained a large negative bias, or reader 1 maintained a strong positive bias. The set of determinations made by reader 3 did not support the determinations made by reader 1 or reader 2, since reader 3 had a much larger positive bias than negative bias when compared with reader 1. However it was shown that on average, reader 1’s age estimates fell somewhere between those of reader 2 and reader 3. Though this provides no evidence that reader 1’s method of age determination is accurate, it does give some indication that reader 1’s estimates are reasonable.

**Age Validation**

The RMI analysis and centrum edge classification study provided some evidence for seasonal band deposition; one light and dark band per year. Typically,
elasmobranchs show a distinct, periodic trend of increasing increment growth from the spring into the summer, and then a decrease in the fall when winter band deposition occurs (Natanson et al. 1995; Carlson et al. 2003). Though the pattern of RMI measurements by date was not ideal, the highest ratio measurements were present in the summer and the lowest ratio measurements were present in the winter. The lack of a clear pattern in the MIR over time could be due to the fact that *R. rhina* have been observed to make large latitudinal movements (McFarlane 2005, Pers. Comm.) It is quite possible that all *R. rhina* individuals do in fact deposit one pair of growth bands according to season, but this growth may occur at slightly different times of the year depending on the individual and the environmental conditions (Jones and Geen 1977; Mugiya et al. 1981; Brothers 1983).

**Age and Growth**

For elasmobranch species with large latitudinal distributions, growth rates tend to be faster and size tends to be smaller for individuals found in the lower latitudes (Parsons 1993b; Branstetter et al. 1978; Baughman and Springer 1950). In this study the 2 parameter VBGF estimated a slower growth parameter for northern individuals \((k = 0.0586)\) than for southern individuals \((k = 0.0656)\). This growth function also estimated a larger asymptotic length for northern *R. rhina* \((L_{\text{inf}} = 170)\) than for southern *R. rhina* \((L_{\text{inf}} = 138)\). These estimates are supported by calculated average total length of skates collected north of Cape Mendocino on the survey, which was larger than the average total length of skates collected in the South. These
results corroborate results from similar research on differences in growth between latitudinal regions (Parsons 1993b; Branstetter et al. 1978; Baughman and Springer 1950) and suggest that northern *R. rhina* grow larger than southern *R. rhina*, and northern *R. rhina* may also grow at a slightly slower rate.

In some elasmobranchs females grow to a larger size and at a slower rate than males (Simpfendorfer et al. 2000), but no significant difference was found between northern male and female growth in this study. Since the maximum size and age for females collected in this study were both greater than the maximum size and age for males, it is likely that female *R. rhina* do live longer and grow larger than males, but it does not prove it. Larger maximum size for females does not necessarily imply a significant difference in growth between males and females. It is quite possible that the growth for males and females is similar but males mature at younger age thus slowing their growth rate at an earlier time in their lives. It may be evolutionarily advantageous for females to achieve a greater size before they become reproductively mature, and a longer life span for females may help increase lifetime fecundity.

The asymptotic length estimate for individuals collected north of Cape Mendocino was much higher than presumed, given the maximum known length for *R. rhina*. One explanation for this could be that there was not enough data to establish an asymptote because older-aged individuals were under-represented in the sample. There are three possibilities for why this could have occurred: A) *R. rhina* primarily exist in a region that was not sampled, B) the sampling gear did not fully select for larger individuals, or C) because older-aged individuals did once exist in greater
numbers, but due to fishing impacts over time, it has become rare for an individual to live to the maximum age or grow to the maximum size.

Regarding supposition A, close to the entire known depth range for *R. rhina* was sampled during the survey; however, the geographic range of *R. rhina* extends up to Alaska. So it is possible that larger, older individuals primarily exist at higher latitudinal regions than those sampled in this study. Differences in the length frequency distributions between survey samples and commercial samples indicate that survey sampling gear did not fully select for large skates (Figures 3 and 5). However, the northern survey collection was supplemented with large individuals from the commercial samples when performing the age at length calculations.

Supposition C cannot be dismissed, as *R. rhina* has probably been caught as bycatch on the West Coast for as long as the groundfish bottom-trawl fishery has been operating, because they are vulnerable to this non-selective gear type.

A final possible reason for the seemingly large $L_{inf}$ values and lower than expected growth parameters is inaccurate age estimations. It is common for growth bands to converge as they reach the edge of the centrum axis particularly after somatic growth slows down. Therefore, it seems possible that growth bands near the edge of the axes are sometimes been misinterpreted, and larger individuals have been under-aged. An oxytetracycline (OTC) tagging study, including larger-sized individuals, would help to resolve questionable annual growth band patterns for older-aged individuals. The possibility that *R. rhina* have been over-aged in this study does not seem likely, given that a recent age and growth study for *R. rhina* off
the coast of British Columbia reported a maximum age of 23 (McFarlane, Per. Comm., 2005). Only 3 individuals in this study were aged older than 20 years. If skates are capable of making large latitudinal movements, it is reasonable to think that *R. rhina* as old as 23 years may be found off the coast of Oregon.

Though the von Bertalanffy growth parameters, $L_{\infty}$ and $k$, calculated for *R. rhina* in this study may not be completely correct for reasons stated above, growth parameters near 0.05 have been calculated for several skate species with maximum observed lengths or estimated asymptotic lengths similar to those found for *R. rhina* in this study (Table 8). The results from these previous studies can provide some support for the accuracy von Bertalanffy growth curves estimated for *R. rhina* in this study.

<table>
<thead>
<tr>
<th>Species</th>
<th>Source</th>
<th>Location</th>
<th>Sex</th>
<th>$L_{\infty}$</th>
<th>$k$</th>
<th>Max Age</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Leucoraja naevus</em></td>
<td>DuBuit (1972)</td>
<td>Celtic Sea</td>
<td>Both</td>
<td>91.64</td>
<td>0.019</td>
<td>13-14</td>
</tr>
<tr>
<td><em>Leucoraja ocellata</em></td>
<td>Sulikowski et al. (2002)</td>
<td>Gulf of Maine</td>
<td>Female</td>
<td>137.4</td>
<td>0.059</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Male</td>
<td>121.8</td>
<td>0.074</td>
<td>19</td>
</tr>
<tr>
<td><em>Raja miraletus</em></td>
<td>Abdel-Aziz (1992)</td>
<td>Off Egypt</td>
<td>Both</td>
<td>87.32 DW</td>
<td>0.08</td>
<td>18</td>
</tr>
<tr>
<td><em>Raja laevis</em></td>
<td>Holden (1974)</td>
<td>NW Atlantic</td>
<td>Both</td>
<td>152</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of this study have shown that *R. rhina* found north of Cape Mendocino live longer, reach a larger maximum size and may grow at a slower rate than *R. rhina* found South of Cape Mendocino. It is suggested that management decisions regarding this species in the future make note of this latitudinal stock delineation. Further research on the age and growth of *R. rhina* found south of Cape Mendocino should be conducted, with an emphasis on collecting as many large-sized
individuals as possible. Additionally this study has provided some evidence for greater longevity and larger maximum lengths for female *R. rhina* versus male *R. rhina.*

Overall the growth parameters estimated for *R. rhina* in this study are low compared to most elasmobranch species, and the estimated $L_{\text{inf}}$ values and observed maximum lengths are large compared to most skate species. Elasmobranch species in general tend to be more sensitive to fisheries mortality due to their slow growth and large size. Maximum known length was found to be the life history parameter that had the most significant relationship with exploitation response (Dulvy et al. 2000). Frisk and co-workers (2001) determined that elasmobranchs greater than 100 cm in length have life history traits (slower growth, late maturity) that place them at a greater risk of population decline, and equally important, low potential population increases, due to slower population growth rates. In this study female *R. rhina* were found to attain a maximum length of 142 cm. The results of this study and the findings of past studies indicate that *R. rhina* may not be resilient to large fishing impacts over time, and management restrictions may need to be put in place to avoid the overexploitation of *R. rhina.*
Maturity and reproduction of the longnose skate, *Raja rhina*, off the coast of Washington, Oregon and California

Josie Thompson

Not yet submitted
CHAPTER 3. REPRODUCTION AND MATURITY

ABSTRACT

Between February 2003 and November 2004, 321 female and 229 male longnose skate (*Raja rhina*) were collected from commercial bottom-trawl landings made in Oregon and from catches made by the NOAA Fisheries annual West Coast groundfish survey along the length of the U.S. West Coast. Reproductive organs were examined to determine size and age at maturity and to characterize the reproductive cycle. Females collected North of Cape Mendocino ranged in size from 15.5 to 142.3 cm total length and males ranged in size from 26.9 to 130 cm total length. Females collected South of Cape Mendocino ranged in size from 18.1 to 104.3 cm total length and males ranged in size from 19.2 to 101.5 cm total length. In females, oviducal gland width and uterus width measurements related to body length and showed a rapid increase in size around the size of maturity. North of Cape Mendocino females matured between 89.7 and 125.6 cm total length and 11 and 18 years. 50% were mature at 120.2 cm and age 16. South of Cape Mendocino females matured between 76.1 and 99.2 cm total length and 11 and 14 years. 50% were mature at 90 cm and 13 years. Male maturity was well-described by a rapid increase in the clasper length to body length ratio combined with clasper calcification. North of Cape Mendocino males matured between 65.1 and 111 cm total length and 7 and 17 years. 50% were mature at 108 cm and 14 years. South of Cape Mendocino males matured between 66.7 and 90.9 cm total length and 9 and 12 years. 50% were mature at 81 cm and 11 years. No strong evidence was found for seasonality in the reproductive cycles.
though there was minimal evidence for greater reproductive activity during the summer months.

INTRODUCTION

Skates (family: Rajidae) are common inhabitants of temperate demersal ecosystems around the world (Last 1997). Many maturity studies have been conducted for skate species, though the reproductive cycle has only been characterized for a few species. Skate are oviparous, have internal fertilization and deposit tough, leathery egg cases on the ocean floor, inside of which the young develop. The reproductive ecology of many skate species is unknown (Walmsley-Hart et al. 1999). Some studies have indicated that skates whose depth ranges occur on the continental slope may deposit egg-cases year-round, while species occurring on the continental shelf may have seasonal reproductive cycles (Hamlett and Koob 1999). The reproductive cycle of individual females, or the length of time during which individuals are reproductively active, is not known for any skate species (Hamlett and Koob 1999). Skates held in captivity have been observed to produce one or two egg cases every one to four days during the height of the season (Holden 1974). The egg-laying rates observed in these studies appeared to be dependent upon temperature, and maximum rates occurred when temperatures were rising (Holden 1974). This may explain the evidence for seasonal reproduction in shallow-water species but not deep-water species. While the Rajidae are the most fecund of all
elasmobranchs, it is estimated that they produce less than 100 egg capsules per year, and during some years they may not produce any (Holden 1974).

In Zeiner and Wolf’s (1993) study on the age, growth and maturity of longnose skates, females reached full maturity between the ages of 10 to 12, and males, between the ages of 10 and 11. Zeiner and Wolf (1993) used the following criteria to determine maturity: for males, the clasper length to body length ratio and clasper calcification; for females, the presence of vitellogenic ova at least 10 mm in diameter.

Clasper length and associated calcification is a well-accepted method for estimating male maturity (Martin and Cailliet 1988; Snelson et al. 1988; Stehmann 2002; Mabragana et al. 2002). There is a rapid change in clasper length relative to body size and clasper rigidity once a male becomes reproductively active. Other indicators of male maturity, such as number of rows in the alar thorn patch, and coiling of the efferent ductus can also be used in order to attain more accurate maturity estimations (Mabragana et al, 2002).

Accurately assessing maturity in female skates may be a bit more challenging. According to Koob and co-workers (1986), ovarian follicles in different stages of development are present in females at all times during egg production. The ovaries of inactive females contain only small follicles (Koob et al. 1986). It is assumed that female maturity for skate and ray species can be macroscopically assessed using maximum follicle size and ovary appearance (Mabragana et al. 2002; Smith and Merriner 1986; Martin and Cailliet 1988). However, if egg production does not occur
year-round, it is possible that a mature female in a resting period may be mistaken as being immature. For some species of fish such as the petrale sole (*Eopsetta jordani*), maturity status cannot be determined accurately using macroscopic assessment during certain seasons such as the summertime (Hannah et al. 2002). Histological analysis of the gonads is the most accurate method for determining stages of maturity, and can be used to validate macroscopic assessment methods.

**OBJECTIVES**

The objectives of this study were to assess the reproductive status of male and female *Raja rhina* along the U.S. West Coast by, including calculating length and age at maturity for each sex, testing for latitudinal differences in the onset of maturity and looking for indications of seasonality in the reproductive cycle.

**MATERIALS AND METHODS**

**Sampling Design**

Skate samples were collected during the NOAA Fisheries West Coast groundfish survey for comparisons between latitudinal regions. This survey, designed to cover the Pacific coast from 55-1280 meters, samples in a stratified random method by selecting random sites from a pre-determined sampling grid. Samples were collected between July 10th and August 15th from Coos Bay, Oregon to the US/Mexico border, and between August 30th and September 15th from Cape Flattery, Washington to Astoria, Oregon. In addition, skate samples were collected
on a near monthly basis for one year from groundfish trawl landings made at the
Pacific Shrimp seafood processing plant in Newport, Oregon.

Survey Data Collection

The following data were collected for all NOAA Fisheries West Coast
groundfish survey samples: date of catch, haul location and depth, sea surface
temperature, total length from snout tip to tail tip (0.1 cm), disc width from wing tip
to wing tip (0.1 cm), total weight to the nearest 0.01 kg, sex, total gonad mass (left
and right) to the nearest 0.01kg, and liver weight to the nearest 0.01kg. Liver
weights and gonad weights were not collected for specimens with livers or gonads
weighing less than 0.01 kg due to limitations with the scale. All weights recorded
aboard the survey were measured using an electric balance. The aforementioned data
were not recorded for every longnose skate caught while aboard the survey due to
time restrictions, though the majority of those caught were sampled.

The following maturity data were collected for all males: length of longest
clasper (from posterior of cloaca to tip of clasper, mm) and clasper length as a percent
of total length, degree of calcification of claspers (flexible, partially flexible or rigid),
sperm duct width (specimen’s left side, mm), presence and amount of coiling of the
sperm ducts. As time permitted, a section of the testes was removed from a sub-
sample of mature or maturing males caught on each survey leg. These were
preserved in 10% buffered formalin (1:20 tissue to formalin volume ratio) for later
possible histological analyses.
The following maturity data were collected for all females: uterus width (specimen's left side, mid-section, mm), oviducal gland width (widest, mm), appearance of ova and ovaries (vitellogenic or not), and maximum ova diameter (MOD) (mm). Presence of forming or formed egg case in the uteri was also noted. As time permitted, a section of the ovaries was removed from the mature or maturing females and preserved in 10% buffered formalin (1:20 tissue to formalin ratio) for later possible histological analyses. All reproductive measurements were made to the nearest millimeter using Vernier calipers.

Port Data Collection

For all monthly, Oregon port samples, the following data was collected: boat name, landing date, total length, disc width, total weight, and sex. Total weights were measured to the nearest 0.1 kg using a Chantillon IN-series hand scale. The following data was collected for all males: length of longest clasper, clasper calcification, sperm duct width, and coiling of the efferent ducts. The following data was collected for all females: oviducal gland width, uterus width, maximum ova diameter (MOD), and presence of vitellogenic ova. Liver and gonad weights were attempted for monthly samples, but could not be feasibly and accurately attained.

Reproductive Analyses

The gonadosomatic index (GSI = total gonad mass/total body mass*100) was calculated for all females and males. The hepatosomatic index (HSI = total liver
mass/total mass*100) as well as the gonad weight at age was calculated for all females. A two-sample t-test was used to test for statistically significant differences in HSI and GSI between mature and immature individuals of both sexes. For mature individuals the following temporal data were plotted by date in order to make inferences about the timing of the reproductive cycle: Female; maximum ova diameter, frequency of egg cases in the uteri, uterus width index (UWI, uterus width as a % of TL, Mollet et al. 2000), GSI and HSI. Males: sperm duct width as a % of TL, and GSI.

**Maturity Assessment**

Assessment of maturity was done based on the work of Mabragana and co-workers (2002). Males were divided into three categories: immature (short, non-calcified claspers, non-developed alar thorn patch, straight sperm duct), maturing (long, calcifying claspers (flexible, though not soft), developing alar thorn patch, sperm ducts beginning to coil) and mature (long fully-calcified (cannot be bent) claspers, fully grown alar thorn patch, highly coiled sperm duct) (Figure 33) (Mabragana et al. 2002). Male maturity was also determined from the relationship between clasper length and total length. Females were classified as immature when they had undeveloped, thread-like uteri, ovaries containing non-vitellogenic ovarian follicles <10 mm in diameter, and undeveloped oviducal glands (Figure 34). Females were classified as mature when they had wide uteri, vitellogenic ovarian follicles > 10
mm diameter, and widened oviducal glands (Figure 36). Oviducal width and uterus width were also examined as potentially useful indicators of female maturity.

A binary code was used for analysis of age and length at maturity (0 = immature, 1 = mature). All individuals not considered fully mature were classified as being immature. Logistic regression was used to fit sigmoid curves for length-maturity and age-maturity (Hannah et al. 2002). The model fitted had the following form

$$P_x = \frac{e^{(a+bx)}}{1 + e^{(a+bx)}},$$

where $P$ = the probability that a fish is mature in a given length or age category, $x$, and $a$ and $b$ are the parameters that define the shape and location of the curve.

Figure 33. Photographs of immature (A) and mature (B) male *Raja rhina* claspers as defined in this study.
RESULTS

Data Collection

Between June 17\textsuperscript{th} and September 8\textsuperscript{th}, 2003, a total of 317 \textit{R. rhina} were collected along the U.S. West Coast while aboard the annual groundfish survey: 149 males (19 to 124 cm) and 168 females (18 to 125 cm) (Figure 3). Survey samples were collected along the majority of the U.S. West Coast except between 43°30'00" N and 46°50'00" N latitude (Table 3 and Figure 4). Close to the entire known depth range for \textit{Raja rhina} was sampled in each region along the coast. The portion of the depth range which was not sampled in each region ranged between 10 and 60 meters, the most shallow portion of the species depth range (Table 4).

In addition to the survey sample collection, between February 2003 and November 2004, a total of 234 \textit{R. rhina} were collected from trawl tows made off the
coast of Oregon and landed in the port of Newport, Oregon: 86 males (31 to 129 cm) and 148 females (19 to 142 cm) (Figure 5). The majority of these monthly collections came from commercial landings, though two were provided by research survey catches. The source of the August 2003 sample was a flatfish trawl survey conducted by the Oregon Department of Fish and Wildlife (ODFW) and the June 2004 sample was collected by the West Coast Groundfish survey team. Both samples were collected from trawls made off the coast of Oregon. Samples were collected during 9 different months of the year. Sample size by month ranged between 17 and 27 individuals (Figure 6). The length range of individuals from commercial catch landings ranged from 50 to 142 cm (Figure 5).

All monthly commercial samples were caught off the coast of Oregon, based on fish ticket and logbook data. A map of general start and finish locations for all but one commercial landing sampled was provided by Oregon Department of Fish and Wildlife (ODFW) (Figure 7). The sample from April 2004 could not be accounted for in the fish ticket data.

**Reproductive Analyses: Male**

Clasper length increased as a function of total body length in male longnose skate. Clasper length for immature individuals north of Cape Mendocino, ranged from 1.6 to 24.1 cm, averaged 12.2\% (SE= 0.44\%, n = 118) of total body length and ranged between 3.4\% to 31.9\% total body length, and quickly increased to 25 cm for individuals ranging between 80-110 cm total length (Figure 35). Clasper length for
mature individuals ranged from 21.7 to 43 cm, averaged 29.4% (SE = 0.54%, n=34) of total body length, and ranged between 25.9% and 40.7%. Using a two-sample t-test, a statistically significant difference between the average immature and mature CL:TL ratio was found (t-stat = 20.00, d.f. 150, p < 0.01) in the northern region.

South of Cape Mendocino, clasper length for immature individuals ranged from 1.4 to 13.4 cm, averaged 9.4% (SE= 0.34%, n = 54) of total body length and ranged between 5.2% to 16.6% total body length, but quickly increased to 20-25 cm for individuals ranging between 70 to 90 cm total length (Figure 36). Clasper length for mature individuals ranged from 20.3 to 29.2 cm, averaged 29.8% (SE = 0.53%, n=34) of total body length, and ranged between 26.1% and 32.0%. Using a two-sample t-test, a statistically significant difference between the average immature and mature CL:TL ratio was found (t-stat = 32.36 d.f. 18, p = 1.05E -17) in the South region. When comparing the CL:TL ratio of mature individuals found North of Cape Mendocino with those found South of Point Conception (on the survey) the difference was not significant (t-stat = 0.673 d.f. 15 , p = 0.511).
Figure 35. The relationship between clasper length and total body length for immature and mature males found North of Cape Mendocino (including all survey and commercial samples).

Figure 36. The relationship between clasper length and total body length for immature and mature males found South of Cape Mendocino (survey samples only).
Similar to clasper length, sperm duct width increased abruptly for maturing individuals in both the North and South regions (Figures 37 and 38). The sperm ducts enlarge as an individual is maturing, but before the claspers are fully calcified, and the male is truly mature. Sperm duct width for immature individuals North of Cape Mendocino averaged 0.64% (SE = 0.05%, n = 73) of total body length and ranged between 0.15% to 2.52% total body length. The width of the efferent ducts for mature individuals averaged 2.4% (SE = 0.07%, n = 27) of total body length, and ranged between 1.67% and 3.44%. Using a two-sample t-test, a statistically significant difference was found (t-stat = 19.3453, d.f. 53, p = 5.5 E-26) between the average immature and mature sperm duct width to total length ratio in the North region.

Sperm duct width for immature individuals found South of Cape Mendocino averaged 0.57% (SE = 0.10%, n = 16) of total body length and ranged between 0.24% to 1.93% total body length. Sperm duct width for mature individuals averaged 2.11% (SE = 0.24%, n = 8) of total body length, and ranged between 1.08% and 3.00%. A statistically significant latitudinal difference in sperm duct to body length ratio for mature males was not found (t-stat = 1.09, d.f. 13, p = 0.297).
Figure 37. The relationship between sperm duct width and total length for immature and mature males caught North of Cape Mendocino.

Figure 38. The relationship between sperm duct width and total length for immature and mature males caught South of Cape Mendocino.
There was no correlation between male GSI and total length ($R^2 = 0.0222$). GSI ratios for males ranged between 0.17 % and 2.22 % of body weight. A difference between the GSI for immature and mature individuals was found, although there was considerable overlap in the GSI of immature males (range: 0.17-2%, $n = 39$) with that of fully mature males (range: 0.34-2.22 %, $n = 22$) (Figure 39). The mean GSI for mature males of 1.47% (SE=0.09%) was greater than GSI of immature males of 0.76% (SE=0.07%) and a two-sample t-test showed that the difference was statistically significant (2- tailed t-stat = 6.709, d.f. 57, $p = 4.86 \times 10^{-9}$). Gonad weights were not measured for individuals smaller than 45 cm total length.

Figure 39. Range of GSI measurements for immature (maturity code = 0) and mature (1) males.
Sperm duct width index (% of total body length) and GSI data for mature males were graphed by month to check for seasonality in the reproductive cycle. However few data points existed for mature individuals and the data provided no evidence for seasonality.

Reproductive Analyses: Female

The size of female reproductive organs also increased with an increase in body size. Oviducal gland width proved to be a good indicator of maturity. There was a rapid increase in oviducal gland width for maturing females, with only minor overlap in the range of immature and mature oviducal gland widths. North of Cape Mendocino, oviducal gland width for immature individuals averaged 15.6 mm (SE= 0.781, n = 166) and ranged between 3 to 48 mm, but quickly increased to ~ 50 mm for individuals ranging between 90-120 cm total length (Figure 40). Oviducal gland width for mature individuals averaged 65.4 mm (SE = 1.98, n=29), and ranged between 45 and 81mm. South of Cape Mendocino, oviducal gland width for immature individuals averaged 12.1 mm (SE= 1.39, n = 52) and ranged between 3 to 39mm, but quickly increased for individuals ranging between 80 to 100 cm total length (Figure 41). Oviducal width for mature individuals averaged 51mm (SE = 4.12, n= 8), and ranged between 33 and 71mm.
Figure 40. The relationship between oviducal gland width and total length for females collected North of Cape Mendocino.

Figure 41. The relationship between oviducal gland width and total length for females collected South of Cape Mendocino.
Similar to oviducal gland width, uterus width also increased rapidly during the onset of maturity. North of Cape Mendocino, uterus width increased rapidly from ~5 mm to ~20 mm for individuals between 100 and 120 cm total length (Figure 42). In the South, this rapid growth of the uterus in maturing females was not quite as obvious (Figure 43).

The uterus width index (UWI, uterus width as percent of total length) was used to compare immature and mature females and northern and southern regions. North of Cape Mendocino, the UWI for immature individuals averaged 0.68% (SE = 0.025%, n = 159) of total body length and ranged between 0.25% to 2.1% total body length. UWI for mature individuals averaged 2.12% (SE = 0.11%, n=24) of total body length, and ranged between 1.5% and 3.7%. Using a two-sample t-test, a statistically significant difference between the average immature and mature UWI was found (t-stat = 18.7689, d.f. 181, p = 2.47 E-44) in the North region. For females collected South of Cape Mendocino the uterus width index for immature individuals averaged 0.0789% (SE = 0.058%, n = 59) of total body length and ranged between 0.42% to 2.48% total body length. UWI for mature individuals averaged 1.7% (SE = 0.17%, n=8) of total body length, and ranged between 1.15% and 2.53%. Using a two-sample t-test, a statistically significant difference between the average immature and mature UWI was found for the southern region (t-stat = 5.80 d.f. 65, p = 2.1 E-7). A statistically significant latitudinal difference in uterus width to body length ratio for mature females was not found when comparing skates collected on the 2003 survey.
Figure 42. Relationship between uterus width and total length for all immature and mature females collected North of Cape Mendocino.

Figure 43. Relationship between uterus width and total length for all immature and mature females collected South of Cape Mendocino.
The maximum ova diameter (MOD) increased with body size, particularly after maturity (Figures 44 and 45). There was almost no overlap in the MOD range between immature and mature females. The MOD of immature fish ranged from 1 to 5 mm (n=14) for southern females and from 1 to 10 mm (n=84) for northern females. The MOD of mature fish ranged from 10-21 mm for southern females (n=5) and 10 to 40 for southern females (n=23).

Figure 44. Relationship between maximum ova diameter (MOD) and total length for immature and mature females collected North of Cape Mendocino.
Gonad weight generally increased with age (Figure 46). There was, however, no correlation between female GSI and total length, $R^2 = 0.002$ (Figure 47). The GSI for all females ranged between 0.23% and 3.29 % of body weight, and no significant latitudinal difference was found in female GSI. There was considerable overlap in the GSI of immature females (range: 0.23-2.55%, $n = 58$) and that of fully mature females (range: 0.28-3.294 %, $n = 14$). However, the mean GSI of mature females of 1.63% (SE=0.26%) was greater than GSI of immature females of 0.82% (SE=0.056%) (t-stat = -3.12, d.f. 14, $p = 0.0075$). Gonad weights were not measured for females smaller than 50 cm total length.

Figure 45. Relationship between maximum ova diameter (MOD) and total length for immature and mature females collected South of Cape Mendocino.
Figure 46. Relationship between age and ovary weight for females collected during the survey from both regions.

Figure 47. Plot of immature and mature female GSI versus total length for both regions.
There was a correlation between female HSI and total length ($R^2 = 0.423$; Figure 48). No significant latitudinal difference was found in female HSI ratios. The HSI ratios for all females ranged between 0.62% and 11.26% of body weight. There was a high degree of overlap in the HSI of immature females (range: 0.62-11.26%, $n = 88$) and that of fully mature females (range: 3.81-10.67%, $n = 14$). The mean HSI of mature females of 8.23% ($SE = 0.658\%$) was greater than HSI of immature females of 6.72% ($SE = 0.236\%$) ($t$-stat = 2.14, d.f. 17, $p = 0.0471$). Liver weights were not measured for females smaller than 38 cm total length.

Figure 48. Hepatosomatic index of immature and mature females collected during the 2003 NWFSC bottom trawl groundfish survey plotted by total length.
There was no obvious seasonal pattern in the reproductive cycle based on analysis of UWI and HSI data (Figures 49 and 50). However MOD and GSI values both show a decreasing trend from summer months through September (Figures 51 and 52). This only suggests that fewer females are reproductively active in the fall season as compared to the summer, but this may also be true of winter and spring. It is still likely that the , but it appears that female reproductive cycle for R. rhina is not highly seasonal. This is supported by the fact that forming or fully formed egg cases were found in one or both uteri of females collected North of Cape Mendocino during four different months of the year (January, March, July and September) (Figure 53).

Figure 49. Uterus width index of all mature females collected North of Cape Mendocino graphed by date of catch.
Figure 50. Hepatosomatic index of mature females by date (collected during 2003 survey).

Figure 51. Maximum ova diameter of mature females and the monthly average plotted by date of capture (2003-2004).
Figure 52. Gonadosomatic index ratios of mature females by date of catch in Summer of 2003

Figure 53. Number of egg cases found in the uteri of females found North of Cape Mendocino according to date in 2003 and 2004.
Length and Age at 50 % Maturity

The maturity data were used to fit age- and length-at-maturity relationships for male and female *R. rhina* collected north and south of Cape Mendocino (Figures 54-57). The fitted relationships indicated that male *R. rhina* found north of Cape Mendocino were 50% mature at about 108 cm and 14 years of age (Figure 54), and males matured between 65.1 and 111 cm total length and 7 and 17 years of age. South of Cape Mendocino the fitted relationships showed that males were 50% mature at about 81 cm and 11 years of age (Figure 55), and males matured between 66.7 and 90.9 cm total length and 9 and 12 years of age.

The fitted relationships indicated that female *R. rhina* found north of Cape Mendocino were 50% mature at about 120 cm and 16 years of age (Figure 56), and females matured between 89.7 and 125.6 cm total length and 11 and 18 years of age. The fitted relationships for females collected south of Cape Mendocino indicated that 50% were mature at 90 cm and 13 years of age (Figure 57), and females matured between 76.1 and 99.2 cm total length and 11 and 14 years of age.
Figure 54. Proportion mature for male *R. rhina* from north of Cape Mendocino, by age and length. The fitted curve is also shown.
Figure 55. Proportion mature for male *R. rhina* from south of Cape Mendocino, by age and length. The fitted curve is also shown.
Figure 56. Proportion mature for female *R. rhina* from north of Cape Mendocino, by age and length. The fitted curve is also shown.
Figure 57. Proportion mature for female *R. rhina* from south of Cape Mendocino, by age and length. The fitted curve is also shown.
DISCUSSION

Fish species with broad latitudinal distributions often demonstrate differential growth rates by location, with individuals found in lower latitudes having higher growth rates and an earlier age at maturity than individuals found in higher latitudes (Parsons 1993a). A similar difference in maturation rates is often true between males and females, with males growing faster and maturing earlier. The differences in length and age at 50% maturity between males and females and between northern and southern latitudes found in this study corroborated differences found in the life histories of northern and southern bonnethead sharks (*Sphyrna tiburo*) (Parsons 1993a). The average and maximum size of skates collected north of Cape Mendocino on the survey was larger than those collected in the South.

Although southern females reached 50% maturity at a younger age than northern females, no statistically significant differences were found for UWI, oviducal gland width, GSI or HSI between mature females in each region. No statistically significant differences were found in the SDWI or CL:TL ratio between northern and southern mature males either, even though age-at 50% maturity was also found to be younger for southern males. This indicates that southern individuals may grow at a faster rate, at least until they become reproductively mature.

The results from this study indicate that both male and female *R. rhina* reach sexual maturity late in life and at a stage which seems contrary to typical life history strategy. However, many other species of skates have also been found to reach maturity at sizes close to their maximum observed length and during the latter portion.
of their known life span. *Leucoraja naevus* of the Celtic Sea has a maximum age of 13 to 14 and matures at age 9 (DuBuit 1972). Francis et al. (2001) estimated age at first maturity for *Dipturus innominatus* to be 13 with a maximum age of 24. The Aleutian skate (*Bathyraja aleutica*), has a maximum observed length of 133 cm and was found to reach first maturity at 119 cm (Ishiyama 1958). The barndoor skate, *R. laevis*, has been found to achieve a maximum length of 152 cm and reach 50% maturity at lengths of 108 to 116 (Casey and Meyers, 1998; Gedamke et al. 2001). Zeiner and Wolf (1993) estimated age at full maturity for *R. rhina* females to be 10 or 11 with a maximum age of 12.

The methods used to assess maturity in this study, which are mostly based on the size of reproductive organs, are commonly employed in reproductive studies of oviparous elasmobranchs (Mabragana et al. 2002; Smith and Merriner 1986; Martin and Cailliet 1988). In this study oviducal gland and uterus width measurements were consistently larger in mature versus immature females. There was also a significant difference between immature and mature males individuals for all measurements made. Both clasper length and sperm duct width increased rapidly during maturation. The small overlap in the size ranges of claspers and sperm ducts for immature and mature males can be explained by the fact that claspers usually grow significantly before calcification occurs and males become reproductively mature. These results therefore provide some indication that maturity status was accurately determined for both sexes.
Though the methods used for assessing maturity are commonly used in reproductive studies for Rajidae species, it does not necessarily mean that these methods are accurate for determining size and age at first or 50% maturity for *R. rhina*. It seems highly unlikely that 50% of all females do not reach maturity until age 16 in the northern region with a maximum age of 22 years and age 13 in the southern region with a maximum age found of 16 (though true maximum age in the south is likely to be slightly higher). However, it is important to remember that females were found to be mature in both regions as early as 11 years of age. Even so, there were a few females in this study that were classified as immature because they did not meet the all of the criteria of a mature individual, even though they had oviducal glands and uteri similar in size to those of a mature female. It is possible that if *R. rhina* females exhibit periods of reproductive quiescence, during which time no large, vitellogenic ova are present in the ovaries, mature females could be incorrectly classified as immature. If this is the case for *R. rhina* then it is possible that age at 50% maturity is lower than the estimates made in this study.

Thus far, no study (including this one) has provided evidence for a true resting stage in the reproductive cycle of a skate or ray species. Egg cases were found in the uteri of five females for four different months and seasons of the year, although this does not prove that all females are producing egg cases consistently throughout the year. The GSI and MOD measurements show greater reproductive activity in the summer months, and less in the month of September. It is important to note that because the scale used in this study did not have sufficient resolution to weigh small
amounts of tissue, gonad and liver weights may not have been sufficiently accurate, especially for the smaller individuals. Movement on the survey vessel may have also had a disproportionate effect on smaller samples.

Overall, the results of this study suggest that reproductive maturity in *R. rhina* may occur later in life than previously calculated by Zeiner and Wolf, (1993) especially for individuals from higher latitudes where individuals achieve larger maximum size. However, it is suggested that the estimates for age at 50% maturity found in this study are too high due to the methods used for maturity assessment, and this may be particularly true for females. It is also suggested that before further maturity work is conducted on *R. rhina*, the current methods used to assess maturity in skates are validated by comparing visual and histological determinations for females collected throughout the year. More accurate determinations of maturity than those found in this study may also be achieved by collecting a greater number of larger individuals, especially south of Cape Mendocino.

Elasmobranchs, including skates, are characteristically long-lived and have slow growth (Holden 1974; Holts 1988; Heppell et al. 1999). If skate species like *R. rhina* mature at a relatively late period in life and have relatively low fecundity, it is likely that fisheries practices could have a significant impact on local populations.
Evaluation of current U.S. West Coast fisheries data for the longnose skate, *Raja rhina*

Josie Thompson

Not yet submitted
CHAPTER 4. EVALUATION OF CURRENT U.S. WEST COAST FISHERIES DATA

INTRODUCTION

Populations of *Raja laevis* in the Northwest Atlantic and *R. batis* in the Irish Sea became locally depleted due to their life history strategies which made them vulnerable to fishing gear at an early age and sensitive to the high rates of fishing mortality they experienced, mostly from bottom trawling practices (Casey and Meyers 1998; Brander 1981; Dulvey et al. 2000). *Raja laevis* and *R. batis* are both species of the family Rajidae, assumed to be the most productive of all elasmobranch families (Holden 1974; Hamlett and Koob 1999). However, the impact of exploitation on a species is largely determined by the number of offspring which survive to maturity, rather than its fecundity (Walker and Hislop 1998; Heppell et al. 1999).

Due to its large initial size, about 20 cm at hatch, *R. laevis* are vulnerable to commercial trawl nets at birth causing a reduction in the number surviving to maturity (Casey and Myers 1998). Brander (1981) estimated that the mortality on immature *R. batis* in the Irish Sea was probably higher than the mortality on mature individuals as young skates were frequently taken in shallow water shrimp nets. Furthermore, both *R. laevis* and *R. batis* mature at a relatively older age, even in comparison to other skate species. *R. batis* reaches sexual maturity at about 11 years (Wheeler 1978). *R. laevis* is expected to have about the same median age at maturity (Myers et al. 1997).

When species with k-selected life history traits experience a rapid increase in fishing mortality, their recruitment rates will fall significantly (Holden 1974; Holts
1988; Heppell et al. 1999). Given what is known, it seems likely that the local
depletion of *R. batis* and *R. laevis* was a result of reduced recruitment caused by
fisheries mortality. In the Irish Sea, several skate species, including *R. batis*, have
been caught as bycatch in shrimp nets since the early 1900’s, and many have also
been targeted by line and trawl gear as part of an actual skate fishery (Brander 1981).
*Raja laevis*, once frequently occurred as incidental catch in Northwest Atlantic
groundfish trawl fisheries, where groundfish is a management term used to describe
all major fish species which live on or near the bottom and are commonly harvested
by bottom-trawl gear. Bottom trawling is a relatively non-selective fishing method; as
the roller gear is pulled along the bottom of the ocean floor, nearly everything in its
path is swept up into the mouth of the net, including fish and benthic invertebrates.

*Raja rhina* shares a similar life history with both *Raja batis* and *Raja laevis*.
*R. rhina* (see chapters 2 and 3). It does not grow nearly as large as *R. batis* (maximum
length ~220 cm; Dulvy et al. 2000), but both reach maturity at a similar age. *Raja
laevis* attains a maximum known total length of 152 cm, matures at age 11, and has
offspring which are usually 18-19 cm in total length at birth (Holden 1974), all very
similar to the results found for *R. rhina*. With this in mind it seems possible that if
elevated fishing mortality for *R. rhina* is sustained over a long period of time, it too
could potentially face the same fate experienced by *R. batis* 50 years ago and by *R.
laevis* 20 years ago. In addition to life history information, fisheries data is also
needed to assess whether *R. rhina* is at risk of being depleted locally or for many
parts of its range. The main objective of this study is to examine extant fishery
independent and fishery dependent data to evaluate whether the *R. rhina*, may face a similar fate to *R. batis* and *R. laevis* unless different management policies are implemented in the near future.

**FISHERY-DEPENDENT INFORMATION**

**A Brief History of Bottom-Trawling Practices in the U.S.**

In the late 1800's over 800 dory schooners were fishing for Atlantic cod from Cape Cod to the Grand Banks, off the coast of Newfoundland. Steam-powered trawling for groundfish began off the coast of New England and Eastern Canada in 1906, and the fleet expanded to 300 vessels by 1930 (NMFS 1999). In the early 1960's factory-based trawlers from Europe and Asia began exploiting groundfish resources in the Northwest Atlantic including hake, haddock, flounder and cod (NMFS 1999). The foreign fleet was eliminated in 1977 except for a few countries which were permitted to harvest the surpluses of a few species. Soon after 1977 U.S. and Canadian fishing efforts quickly expanded, including a two-fold increase in otter-trawling effort (NMFS 1999). Despite increases in fishing effort on groundfish stocks in the Northwest Atlantic throughout the 1980's and early nineties, many stock biomass levels fell to record lows, and so did the commercial landings. In 1973 cod, haddock and hake landings totaled 1.4 million metric tons, and fell to 0.2 million by 1993 (Symes 1997). Some of these stocks, like Northern cod (*Gadus morhua*), have still not recovered despite the implementation of closed fishing areas. The 2003 stock assessment for the Newfoundlanld and Labrador region indicates that biomass of cod
located offshore remains at 1% of the average levels estimated throughout the 1980's (DFO 2004). Though much attention was given to the over-fishing of targeted stocks in the region like cod and haddock, little concern was given to more sensitive bycatch species like *R. laevis* which were also being affected by the overexploitation of groundfish resources.

The first bottom trawling of the U.S. West Coast began in 1876 with the introduction of the paranzella net, a two boat operation, in San Francisco (Goode 1887). The beam trawl was introduced in the Puget Sound area in 1906. However, the trawl fishery did not really begin in the Pacific Northwest until the late 1920's, as diesel engines and other advanced technology became available (PMCC 1999). It was not until 1939 that the first otter-trawler began fishing off of Oregon, and at that point in time, there was no true market for groundfish in the area. They could only be sold for mink food (PMCC 1999).

Exploitation of West Coast groundfish resources increased significantly in 1963 when Soviet and Japanese factory trawlers began targeting Pacific Ocean Perch and Pacific whiting off the coast of the Pacific Northwest, as well as other rockfish species off the California coast (PMCC 1999; NMFS 1999). In 1976, with the adoption of the Magnuson Fisheries Conservation and Management Act, the federal government began subsidizing the growth of the U.S. commercial groundfish fleet, which was primarily composed of bottom-trawlers, and further advances in marine technology improved fishing efficiency even further. In 1977 domestic landings of all groundfish species increased to from 30,000 metric tons per year to 60,000
Groundfish landings peaked at 116,000 t in 1982 (PFMC 1997). Due to a lack of appropriate data and poor management decisions, the domestic fleet continued to expand and overexploit groundfish populations until the early 1990’s, at which time catch levels fell significantly. In 2000, the Secretary of Commerce officially declared the West Coast groundfish fishery in a state of crisis, and amendments were made to the PFMC Fisheries Management Plan to provide guidelines for developing rebuilding plans for species determined to be overfished (Federal Register, October 6th 2000). While seven West Coast groundfish species have now been declared overfished (at or below 25% of unfished biomass), no attention has been given to species which have commonly occurred as bycatch in the trawl fishery, including *R. rhina*.

**West Coast Skate Market History and Commercial Landing Data**

Information regarding skate market history on the West Coast is limited, especially because species-specific landing information for skates has never been required. According to Roedel and Ripley (1950) three skate species have been landed and sold on the U.S. West Coast since the early 1900’s: the big skate (*R. binoculata*), *R. rhina*, and the California skate (*R. inornata*). Collectively, these three species are included among the ten most harvested elasmobranchs in California since 1976 (Martin and Zorzi 1993). Oregon commercial skate landings have been randomly sampled for species, length and sex data since 1995 by the Oregon Department of Fish and Wildlife (ODFW). This data (1995-2005) indicates that the
majority of Oregon commercial skate landings consist of *R. rhina* (81.9% of all individuals sampled and identified). The data show that *R. binoculata* is the only other species landed for processing and comprises 17.9% of the total number of skates sampled from commercial landings and identified.

Regarding processing techniques, the pectoral fins of skates are commonly sold as fresh and fresh-frozen seafood in domestic ethnic markets (mainly in California), or they are dried and salted or dehydrated for the Asian market (Martin and Zorzi 1993). Skate wings can also be processed and sold as "scallops" (Griffiths, et al. 1984; Lamb and Edgel 1986). Roedel and Ripley (1950) found that larger skates were always discarded at sea because the skate wing skinning machines could not accommodate large-size skates.

Judging from the present size distribution of skates landed in Oregon, small skates are now discarded and the larger individuals are kept for processing (Figures 59-64). Length data from ODFW commercial landing samples (1995-2005) included only two *R. rhina* smaller than 50 cm total length. Nearly all skates landed in Oregon are caught by either large footrope or small footrope bottom trawl gear (Figure 58). Small footrope trawl gear is defined as a bottom trawl net with a footrope diameter of 8 inches or smaller, and large footrope trawl gear is larger than 8 inches in diameter (ODFW 2005). A comparison of *R. rhina* length data between these two footrope designs shows that skates caught by large footrope trawls were significantly larger (t-stat = 4.0993; d.f. 2481; p < 0.001) than skates caught by small footrope trawls. Therefore *R. rhina* length frequency data from Oregon commercial landing samples is
presented by both INPFC area and footrope size. Overall there are more females represented in the samples than males, which could be due either to a skewed sex ratio, or differential susceptibility to bottom trawl gear. Generally, the length frequency distributions are fairly similar for all INPFC management regions and between footrope types, except no skate larger than 130 cm total length was caught in the U.S.-Vancouver region. Few *R. rhina* landed in Oregon appear to be caught in the U.S.-Vancouver region. There were many more samples from the U.S.-Vancouver region caught by small footrope gear than large footrope gear, which would explain the size bias in these samples. Of all samples caught in the Columbia region (n = 1575), there were over 200 more caught by small footrope gear. Of all samples caught in the Eureka region (n = 744), there were over 400 more caught by large footrope gear.

![Diagram of a bottom trawl net with footrope gear indicated.](image)

Figure 58. Diagram of a bottom trawl net with footrope gear indicated.
Figure 59. Length frequency distribution of male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by small footrope bottom trawl gear in the U.S. Vancouver INPFC management area. N = 138

Figure 60. Length frequency distribution of male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the U.S. Vancouver INPFC management area. N = 16
Figure 61. Length frequency distribution for male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by small footrope bottom trawl gear in the Columbia INPFC management area. \( N = 909 \)

Figure 62. Length frequency distribution for male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the Columbia INPFC management area. \( N = 668 \)
Eureka

Figure 63. Length frequency distribution for male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by small footrope bottom trawl gear in the Eureka INPFC management area. \( N = 155 \)

Figure 64. Length frequency distribution for male and female *R. rhina* Oregon commercial landing samples (1995-2005) caught by large footrope bottom trawl gear in the Eureka INPFC management area. \( N = 589 \)
From 1916-1992, annual commercial skate landings in California ranged from 50,408 lbs. to 631,291 lbs. (dressed weight) (Martin and Zorzi, 1993). Annual landing totals remained close to 600,000 pounds (dressed weight) during the 1930’s, and since then have remained closer to 150,000 pounds. A large number of skates have been and are currently landed in Oregon and Washington, although historical information is limited. According to the Pacific Fisheries Information Network (PacFIN) landings data, between 1981-1994 annual skate landings ranged between 81,000 pounds (round weight) to 1 million pounds for California, 2,100 to 159,000 pounds (round weight) for Oregon, and 154,000 to 387,000 pounds (round weight) for Washington. In 1995, reported skate landings on the West Coast began increasing significantly, especially in Oregon and California. From 1995 – 2004 annual skate landings (all round weight) ranged between 182,000 to 2,982,000 pounds for California, 261,000 to 2,077,000 for Oregon, and 362,900 to 623,000 pounds for Washington (Figure 65). Though these data may accurately represent total skate landings, they are not species-specific, and they do not include information on discards. Therefore, changes in annual skate fishing mortality (F) by species cannot be extrapolated from this data.

There are several factors that could explain the increase in skate landings beginning in 1996. Landings may have increased in response to market price increases. However, market prices have remained relatively steady in Oregon and California since 1996 (Figure 66). According to Martin and Zorzi (1993), skate landings may partially reflect changes in abundance of other groundfish species, but
direct correlations have been inconsistent in the California landing data. It is possible that skate landing trends are indirectly correlated with success of the target fisheries. Holden (1974) predicted that as traditional species become increasingly exploited, more nations will likely turn to the less productive elasmobranch species. If the target species (i.e. rockfish and/or flatfish) catch limit is low, fishers may decide to supplement their catch with less valuable species, like skates. Recently on the U.S. West coast, several valuable rockfish species have been declared overfished, which has led to major regulation changes and severe reductions in the catch limits for these species. It is very likely the recent increase in skate landings is partially a result of these changes, as fishers are looking for new ways to maximize their revenue per fishing trip.

Figure 65. PacFIN landings data (in 1,000 pounds) for the category “unspecified skates” from 1980 to 2004. The PacFIN database is composed of information from fish landing receipts which are completed by the processing plants and collected by the state fish and wildlife agencies.
Annual skate landing totals from the PacFIN database show that over the last 25 years on the U.S. West coast the most skate landings have been caught in the Eureka management region (5755 mt), followed by Columbia (5700 mt), Monterey (2022 mt), Vancouver (2013 mt) and Conception (311 mt). Landing totals presented separately by gear type and INPFC area show that nearly all skate landings are caught by bottom trawl gear (Figures 67 – 71). This is true for every INPFC management area except Conception, where a substantial proportion of skates landed are also caught by other types of net gear, hook and line and even shrimp trawl gear. Since annual skate landing totals for the Conception region are considerably smaller than landings in all other regions, the contribution of these alternate gear types is insignificant. Proportionally more skates seem to be caught and landed via hook and line in the U.S. Vancouver, Monterey and Conception regions than in the Columbia
and Eureka regions. Similar to annual skate landings presented by state, skate landings for all INPFC regions increased substantially in 1996 and 1997, but only in the Columbia and Vancouver regions has this level increase remained relatively constant.
Figure 67. Total annual skate landings by gear type for the U.S. Vancouver INPFC area.
Figure 68. Total annual skate landings by gear type for the Columbia INPFC area.
Figure 69. Total annual skate landings by gear type for the Eureka INPFC area.
Figure 70. Total annual skate landings by gear type for the Monterey INPFC area.
Figure 71. Total annual skate landings by gear type for the Conception INPFC area.
FISHERY INDEPENDENT INFORMATION

Abundance data for *R. rhina* has been collected by the NOAA Fisheries Pacific West coast groundfish bottom trawl survey every three years since 1977 (Coleman 1986; Weinberg 1984; Coleman 1988; Weinberg et al. 1994; Zimmerman et al. 1994; Wilkins et al. 1998; Shaw et al. 2000; Weinberg et al. 2002). This survey was conducted by the Alaska Fisheries Science Center (AFSC) of NOAA Fisheries from 1977 through 2001 over the continental shelf and shallow slope. In 2004, the responsibility for conducting this tri-annual survey was given to the Fishery Resources Analysis and Monitoring (FRAM) Division of the Northwest Fisheries Science Center (NWFSC) of NOAA Fisheries. Also in 2004, the FRAMD began to conduct the shelf survey annually.

During the years that the AFSC was in charge, the survey design remained fairly consistent, although some aspects of it did evolve. Every three years, the AFSC chartered two commercial trawl vessels to sample 500 to 580 stations between Point Conception, California and North Vancouver Island, Canada. Both vessels conducted the survey South to North in one pass. The average size and available horsepower of the vessels did increase slightly over time. In 1995, 1998 and 2001 both survey vessels were about 125 ft. in length. Track lines lying perpendicular to the shelf break were placed along the coast and sampling stations were selected along these lines. Between 1977 and 1986, more intense sampling efforts were made in areas of presumably high rockfish and Pacific whiting abundance in order to increase the precision of biomass estimates for these commercially important species. In 1989,
when it became clear that the survey gear selectivity for rockfish species was not appropriate for estimating abundance, the survey sampling priorities shifted towards juvenile sablefish and Pacific hake found near the ocean floor. In 1995, the survey sampling design goal changed again, mainly to try and achieve near-to-uniform sampling density along the west coast. For all AFSC survey years, trawl nets were towed along the bottom at each station for 30 minutes at a speed of 3 knots. A replicate Nor'Eastern trawl net design was used during all years of the survey (1977-2004). However in 1986 the lower wing panels were removed and 3 bridles were attached to this area. The net material also changed in 1986 from nylon to polyethylene.

When the NWFSC began conducting the survey, they decided to conduct two survey passes down the coast (North to South from Cape Flattery, WA to the U.S. Mexico border) using four commercial trawlers (2 different vessels per pass). These commercial vessels were considerably smaller in size (~60 – 70 ft. in length) than the vessels chartered by the AFSC. The sampling methodology also changed in 2004. Instead of selecting stations along track lines, the sampling sites were selected randomly from a grid which was fit to the entire survey area. For more information regarding triennial survey sampling methodology and equipment, please consult the following reports: Coleman 1986; Weinberg 1984; Coleman 1988; Weinberg et al. 1994; Zimmerman et al. 1994; Wilkins et al. 1998; Shaw et al. 2000; Weinberg et al. 2002.
Survey Length-Frequency data

Beginning in 2001 the NOAA Fisheries triennial west coast groundfish bottom-trawl survey began to collect length data and sex data for *R. rhina*. Length frequency distributions created from this data are presented by year and region (Figures 72 to 75). As with the commercial landings, there is a higher ratio of females for nearly all size classes, especially the larger classes. There is some evidence that the survey gear may not fully select larger-sized or small-sized skates as compared with medium-sized skates, and has higher selectivity for females as compared with males (Figure 61 to 64). The distribution for individuals collected north of Cape Mendocino in 2001 and 2004 show that very few *R. rhina* larger than 120 cm have been caught by survey gear, and the distribution for the southern region shows that few or no individuals larger than 110 cm are caught. This information is particularly important because the accuracy of biomass and mortality estimates is much more contingent on accurately sampling the largest animals versus the smallest animals.

It is important to note that comparing the the length frequency distributions of survey samples to commercial samples may not necessarily indicate a true difference in gear selectivity. Larger-sized skates could appear more frequently in the commercial landings simply because of high grading, or because fishers fish for skates during times of greater activity when skates are more vulnerable to the gear.
Figure 72. A length-frequency distribution for male, female and unidentified *R. rhina* collected north of Cape Mendocino for the 2001 NOAA Fisheries triennial west coast groundfish bottom trawl survey.

Figure 73. A length frequency distribution for male, female and unidentified *R. rhina* collected south of Cape Mendocino for the 2001 NOAA Fisheries triennial west coast groundfish bottom trawl survey.
Figure 74. A length frequency distribution for male and female *R. rhina* collected north of Cape Mendocino for the 2004 NOAA Fisheries triennial west coast groundfish bottom trawl survey.

Figure 75. A length frequency distribution for male and female *R. rhina* collected south of Cape Mendocino for the 2004 NOAA Fisheries triennial west coast groundfish bottom trawl survey.
Biomass Trends

Catch rates are calculated from West Coast triennial groundfish survey data by using the area swept method by Gunderson and Sample (1980). This method assumes that all fish located within the area swept by the trawl footrope at each station are caught by the net. It also assumes that each species is fairly evenly distributed over its entire range. The catch rates (in kilograms of fish per hectare swept) are then multiplied by the area of each depth stratum for each INPFC region to calculate the biomass for each specific area. Biomass is defined as a measure of the quantity, usually by weight in pounds or metric tons (2,205 pounds = 1 metric ton), of a fish stock at a given time. These estimates can then be examined over time in order to make inferences about the status of the fish stock.

Biomass trends for all INPFC management regions show a general pattern of stability or increase between survey years of 1977 to 2001, and especially between the years of 1995 to 2001 (Figures 76 to 83). In 2004, large changes in survey methods were made, and thus, the data from 2004 has not been included. There is a substantial amount of variance associated with many of these estimates. Survey biomass estimate variance is higher when fewer CPUE data points are available to estimate biomass in a particular region and year. This means, if few survey stations are selected in a particular year and region, the associated biomass estimates will be less accurate and variance will be high. Except for the Monterey region, there appears to be a significant jump in biomass around 1989 for all regions, although there is substantial variance in the estimates for this year. It is important to note that in all
regions except U.S.-Vancouver, biomass estimates reach higher than average levels in 1998 and 2001. This is a particularly interesting trend as these were the years in which survey vessel size and power were greatest. Biomass appears to be greater between the depths of 55-183 meters than from 184-366 meters for all years and regions sampled.

Although there are some similarities between regions, the biomass trend in each region is characteristically different. In the U.S.-Vancouver region, biomass has remained fairly constant over time (Figures 76 and 77). Between 1977 and 2001 biomass has increased most substantially in the Columbia region between depths of 55 and 183 meters as compared with all other areas (Figures 78 and 79). In the Eureka area, biomass peaks in 1989, decreases in '92 and '95 and then increases again in '98 and '01 (Figures 80 and 81). *Raja rhina* biomass also appears to fluctuate greatly in the Monterey area though it has also increased substantially between 1977 and 2001 (Figures 82 and 83).

Despite the high amount of variance associated with many of these estimates, overall there appears to be an increase in *R. rhina* biomass on the west coast between the years of 1977 to 2001. But if it is true that the survey gear is not fully selective for the largest-sized *Raja rhina*, the estimated biomass levels and fluctuations between years do not accurately represent the entire stock. Additionally if an increase in survey vessel size and horsepower improves skate catchability, biomass estimates for 1998 and 2001 may not be comparable to previous year estimates.
Figures 76 and 77. Biomass estimates for *Raja rhina* from West Coast triennial survey data for the INPFC U.S. Vancouver management region (47°30’00” N latitude to ~48°30’N). Depth range 55-183 meters (top), depth range 184-366 meters (lower). Thin black whisker bars represent the 95% confidence range.
Figures 78 and 79. Biomass estimates for *Raja rhina* from West Coast triennial survey data for the INPFC Columbia management region (43°00' N latitude to ~47°30'N) Depth range 55-183 meters (top). Depth range 184-366 meters (bottom). Thin black whisker bars represent the 95% confidence range.
Figures 80 and 81. Biomass estimates for *Raja rhina* from West Coast triennial survey data for the INPFC Eureka management region (40°30' N latitude to ~43°00'N). Depth range 55-183 meters (top). Depth range 184-366 meters (bottom). Thin black whisker bars represent the 95% confidence range.
Figure 82 and 83. Biomass estimates for *Raja rhina* from West Coast triennial survey data for the INPFC Monterey management region (36°00' N latitude to ~ 40°30' N). Depth range 55-183 meters (top). Depth range 184-366 meters (bottom). Thin black whisker bars represent the 95% confidence range.
Total mortality estimate

Total mortality (Z) is the sum of fishing mortality (F) plus natural mortality (M). Ideally, the total instantaneous mortality rate is calculated by tracking the population of one cohort over time using the exponential decay equation:

\[ N_t = N_0 \times e^{-Z \times t} \]

Where \( N_0 \) = number of individuals in a cohort at time 0
\( N_t \) = number of individuals in a cohort \( t \) years later
\( Z \) = instantaneous rate of mortality \( t \) = time

Since only length and sex was data for \( R. \ rhina \) has been collected by the survey in 2001 and 2004, the length data had to be converted to age data and the mortality rate had to be calculated using data for multiple cohorts at a single time,. Therefore, the length data for all individuals caught north of Cape Mendocino during the 2004 NWFSC west coast groundfish bottom trawl survey was converted to age data by rearranging the calculated 2 parameter VBGF for \( R. \ rhina \) collected north of Cape Mendocino:

\[ \text{Age} = \left( \ln \left( \frac{\text{Length} - 14.5 - 170.034}{170.034} \right) \right) / -0.0586 \]
Multiple cohorts were sampled at a single time and the catch at age data was used to calculate $Z$ under the following assumptions:

1) The 2004 survey gear is equally selective of all age classes equal to and greater than the age class with the highest number of individuals sampled.

2) Male and female $R. rhina$ have the same total mortality rates.

3) Recruitment, natural mortality and fishing mortality have remained relatively constant over time.

4) The 2 parameter VBGF used to convert length to age data accurately represents the average growth of northern $R. rhina$ over time.

The catch-at-age data was natural-log transformed and used to create the catch curve (Figure 84). It was assumed that $R. rhina$ were not fully selected by the survey trawl gear until age 3, as this was the age class for which the largest number of individuals were caught. A regression line was fit to the transformed catch-at-age data for males and females combined from the age at full selectivity to the maximum age collected. The slope of these lines gives us the estimated instantaneous mortality rate $Z$ which is demonstrated by rearranging the exponential decay equation:

$$Z = \left( -\ln \left( \frac{N_0}{N_t} \right) \right) t$$

The estimated instantaneous total mortality rate was 0.26, but there are many sources of error associated with this estimate. First of all, assumption number 1 could have been violated if the survey does not fully select for large-sized individuals, as
suggested by the length frequency distributions presented in this chapter. Secondly, if females do live to a greater maximum age than males, as suggested by the age and growth study, then assumption 2 may be violated. Thirdly, since skate landings have increased substantially since 1996 it is likely that fishing mortality has increased over time. Therefore, part of assumption 3 would be violated, unless all skates caught as bycatch experience mortality whether they are discarded or kept for processing, and fishers are not increasingly targeting skates for catch. Finally, as discussed in the age and growth chapter, there was a significant amount of error associated with the age estimates used to calculate the VBGF, and therefore, this curve may not accurately represent average growth of \textit{R. rhina} over its entire lifespan, thus violating assumption 4. While almost all of the assumptions are violated, this is the best estimate of Z that can currently be calculated.

![Catch curve data for male and female \textit{Raja rhina} caught on the 2003 West Coast Groundfish survey, North of Cape Mendocino.](image)

\[ y = -0.2619x + 5.8528 \]
DISCUSSION

If the biomass estimates do accurately represent *R. rhina* abundance over time, it appears that *R. rhina* populations have remained steady over the past twenty years. However this does not rule out the possibility that *R. rhina* populations have been affected by past fishing impacts and bycatch mortality. The survey data series only covers a 20 year time period. If major changes in longnose skate abundance have occurred in the past, then the biomass estimates made from the survey data might not demonstrate a decline as the population may already be low but is currently stable. Also, since *R. rhina* mature at a late age, the effects of increased fishing mortality on the spawning stock biomass which may have occurred over the last 10 to 20 years would not be evident in current biomass trends due to generation time. However, if current biomass trends were evaluated with regard to the age structure of the population, it would be possible to judge the effects of increased fishing mortality at this time.

Biomass estimates from the NOAA Fisheries triennial survey (now the shelf and slope survey) data may not be an accurate means of determining actual changes in biomass over time. Biomass calculation methods assume that all fish found in the path of the trawl are caught in the net and all sizes of skates are fully selected by the gear. However, the difference in length distributions between the survey sample and the commercial sample (found in the life history portion of this study) show that the survey trawl probably does not fully select the larger-sized skates. One explanation for this may be that larger skates are more powerful swimmers which enables them to
escape being caught in the net. It is also possible that large-sized skates are not active
during the daytime, when the survey conducts its sampling, and the survey trawl often
sweeps over them. Since the reliability of biomass estimates is much more contingent
on accurately sampling the largest animals versus the smallest animals, the groundfish
bottom trawl survey gear and methods may not be optimal for tracking the biomass of
*R. rhina*.

Despite the many possible errors associated with survey biomass estimates, it
is still possible that *R. rhina* stocks are currently healthy and there is one possible
explanation for this. If *R. rhina* is truly withstanding current fishing impacts, and also
maturing at a very late stage in life, it must have a very high survival rate. Certain
skate species are known to be scavengers, so perhaps *R. rhina* populations have
profited from high levels of trawl fishery discard over the years (Walker and Hislop
1998). High survival is synonymous with low mortality. Since we know that *R.
rhina* has experienced fishing mortality over the last century, its true natural mortality
value is probably lower than the total mortality value calculated in this study (*Z =
0.26*). But for now, due to a lack of any species-specific fisheries-dependent data for
skates, this is the best natural mortality estimate we can make for *R. rhina*. Natural
mortality values estimated for other skate species fall between 0.08 and 0.6 (Holden
1974; Walker and Hislop 1998; Frisk et al. 2001). Therefore, if *R. rhina* total
mortality is estimated to be 0.26, it is possible that it does have a relatively high
survival rate.
Dulvy and co-workers (2000) looked at changes in community structure for six different skate species in the Irish Sea and Bristol Channel, and found that the larger species (with maximum lengths > 85 cm) declined whereas smaller species increased when skate exploitation was increasing due to a rise in market value. The market value of skates has not increased greatly over the past decade, but skate landings on the U.S. west coast have, and the majority of these landings are composed of *R. rhina*. If traditional groundfish stocks continue to decrease on the west coast, and trip limits for these species remain low, skates will continue to be landed by fishers trying to supplement their catches with less restricted species. This means that if left unchecked, annual skate landings could remain at their current level or continue to increase over time. Since *R. rhina* is a larger skate species as defined by Dulvy and co-workers (2001), the current increase in skate exploitation on the U.S. west coast puts this species at risk, regardless of a relatively high survival rate.
CHAPTER 5. GENERAL CONCLUSIONS

Although there is no definitive trend in longnose skate populations over the last 20 years, it does not mean that they are resistant to future declines due to overfishing. If *R. rhina* currently face the same fishing pressures that *R. batis* and the *R. laevis* once faced, it may only be a matter of time before longnose skate populations decline to overfished status on the West Coast. But in order for these species to be assessed, the appropriate data and information must be in place. The major goal of this study has been to provide some of this much needed information, including the measurement and calculation of basic life history parameters and the summarization of currently available fisheries data, both independent and dependent.

The life history traits of *R. rhina* make for a classic k-selected species which is not resilient to rapid increases in mortality. The calculated growth rates for northern *R. rhina* ($k = 0.0586$) and southern *R. rhina* ($k = 0.0656$) are substantially slower than those calculated by Zeiner and Wolf (1993) (0.25 for males and 0.16 for females), as well lower than those calculated for most other elasmobranch species. Additionally the maximum ages found (North: 20 for males, 22.5 for females, South: 15 for males, 16 for females) and the calculated age-at- 50% maturity (North: 14 for males, 16 for females, South: 11 for males, 13 for females) were much greater than previously reported. These results, though not proven to be absolutely accurate, still show that *R. rhina* exhibits more k-selected life history traits than previously thought and should therefore be of concern to fisheries managers and policy makers.
Effective conservation of skates requires species-specific monitoring of abundance and mortality rates. Abundance data has been collected triannually for *R. rhina* on the continental shelf since 1977, and is now collected for all depth regions by the NWFSC west coast bottom trawl groundfish survey every year. The NWFSC also began collecting length and sex data in 2003. Unfortunately it is possible that the survey methods select poorly for large-sized skates, which will continue to lead to inaccurate estimations of abundance, biomass and mortality. Though these estimates may never be accurate, the survey will continue to provide some useful monitoring information for *R. rhina* and other species.

Despite the improvements made to the bottom trawl groundfish survey, it remains impossible to assess the resilience of a skate species to current fishing mortality because the data needed to estimate skate fishing mortality is non-existent. The west coast observer program recently began collecting species-specific bycatch data for skates, which could be useful towards estimating fishing mortality in the near future. Even so, the commercial fisheries landing data currently collected for skates is still non-species specific, and the length and sex data which has been collected from samples of commercial skate landings by the Oregon Department of Fish and Wildlife since 1995 is usually species-specific, but it is not collected on a regular basis. Without this species-specific commercial landing data, total fishing mortality from all sources can not be calculated.

As the future increase in world population continues to raise the demand for seafood products and as traditional fish species become scarce, seafood marketers and
fishermen will continue to become more reliant on non-traditional fish species such as skates. Species-specific landing data is needed, along with data such as those presented in this study, for managers to accurately predict whether the longnose skate truly is vulnerable to current fishing impacts, and whether or not it can withstand higher rates of exploitation in the future as world demand for seafood increases.

**Bibliography**


Schnute and Fournier


APPENDICES
Appendix A. Definition of clarity ratings (1-5) used in this study to define the readability of each centrum section.

1: Unambiguous band count, clear, complete section

2: Band count unambiguous, but sample of moderate clarity

3: Two band counts possible; recorded estimate is the most likely

4: More than two band counts possible; indefinite banding pattern in one or more sample locations. Best estimate recorded.

5: Discard from analysis; banding pattern irregular or cloudy; limited confidence distinguishing bands. Sample may be damaged.

Appendix B. Guidelines established by Josie Thompson and Wade Smith for ageing vertebral centra cross-sections of *Raja rhina*.

1) The birthmark will be counted as the first visible solid white band outside the focus and near the change in angle of centrum growth.

2) A dark band will only be used for counting if it follows all the way across the centrum axis from the top to the bottom.

3) When uncertain about counting a dark band, go to a higher magnification level and look for change in cell orientation, along with change in color.

4) Also when uncertain, use other arms/axes which may have a clearer banding pattern in the area of concern. This is also a good way to confirm ages.

5) When using more than one axis to count all bands, choose the lower estimate.