Analysis of management options for artisanal fishing of the Bigeye Croaker *Micropogonias megalops*(Gilbert, 1890) in the Upper Gulf of California

E. Alberto Aragón-Noriega,a Wenceslao Valenzuela-Quiñones,b Héctor Esparza-Leal,b Alfredo Ortega-Rubio,c and Gerardo Rodríguez-Quiroz,b*

aCentro de Investigaciones Biológicas del Noroeste, Estero de Bacochibampo, Guaymas, Sonora, México; bCentro Interdisciplinario de Investigación para el Desarrollo Integral Regional, Unidad Sinaloa, Blvd. Juan de Dios Báñez Paredes 250, Guasave, Sinaloa 81101, México; cCentro de Investigaciones Biológicas del Noroeste, La Paz México

Bigeye Croaker (*Micropogonias megalops* Gilbert 1890) is captured in the Upper Gulf of California (UGC) by local community fishers from San Felipe in Baja California, El Golfo de Santa Clara and Puerto Peñasco in Sonora. The calculated sustainable fishery index (SFI) identifies four production periods, one of low capture before 1999 (−1451.49 t year −1); a second of fleet expansion (−2408 t year −1); a third showing a production decline related to overfishing (> 923.85 t year −1); and a fourth of recovery, with standardization of production of about 1057 t year −1 (2004). A GIS survey indicated that almost 84% of the Bigeye Croaker fishery in the UGC occurs within two marine protected areas, of which almost 74% takes place inside the Biosphere Reserve of the UGC, and almost 79% in the Vaquita Refuge Area. Bigeye Croaker captured in the marine protected areas generates a gross profit of around US$501,000 year −1, with a return rate close to 73%. Fishing effort in the marine protected areas needs to undergo an interdisciplinary and complex evaluation due to the presence of endangered species in the region. This requires adequate management practices to enhance marine conservation without compromising fishers’ individual interests. Some approaches to manage this fishery within the protected marine areas are discussed.

**Keywords:** conservation; gross profit; marine protected areas; sustainable fishery

Introduction

Small-scale or artisanal fisheries provide an important source of food and income to coastal communities worldwide. Most of their production is for export, thus enhancing countries’ economies. Although there is not an exact census of how many people are involved in this art, the estimate for Latin America alone is more than 2 million individuals. These fishermen provided production of about 2.5 million t, with a value of US$3 million in 2001 (FAO 2002). This activity is sustained by the capture of one or a variety of aquatic species and its sustainability depends on fish quality, capture season and, most of all, market price (Aguero 1992). Mexico has an important tradition of artisanal fisheries. The Gulf of California is one of the major production areas, and contributes 20% of national marine production using over 50,000 small (artisanal) vessels (Cisneros 2001; SAGARPA 2002).

Based on biological, ecological and oceanographic characteristics, the Gulf of California can be divided into four regions. The northernmost is the Upper Gulf of California (UGC), considered important for finfish catch as well as several estuarine-dependent species (Rámirez-Rojo and Aragón-Noriega 2006). On the UGC coast, the most important economic activities are fisheries and tourism (Greenberg 2005). Two types of commercial fishing take place in the UGC: artisanal and industrial fishing. Artisanal fishing uses 7-m fiber-glass boats with outboard motors and two fishermen. Deployment and retrieval of fishing gear (hook and line, gillnets, pots, longlines) is performed manually (Cisneros 2001). For many years, shrimp fishery was the most important fishery in the region, and was carried out in medium-size vessels (20-m long), but due to bankruptcy in the late 1980s and early 1990s many fishermen have joined together in new artisanal fishing organisations known as cooperatives, comprising fishermen from the three ports of the UGC: Puerto Peñasco (PP) and El Golfo de Santa Clara (GSC) in the State of Sonora and San Felipe (SF) in the State of Baja California. These cooperatives have diversified their fishing to finfish and estuarine-dependent species (Cudney and Turk 1998).

The high profit secured in the region has led to an increase in fishing efforts, which is jeopardizing totoaba (*Totoaba macdonaldi* Gilbert 1890) and the rare vaquita (*Phocoena sinus* Norris 1958). These species are not intentionally captured but accidentally caught in all types of gillnets used in the UGC (Cisneros-Mata et al. 1995; D’Agrosa et al. 2000), and due to their small population sizes, they are at risk of extinction (Rojas-Bracho et al. 2006). The vaquita population is estimated at 150 individuals, and the species is distributed worldwide. Its population appears to be declining by about 10% per year, as a result of increases in artisanal boats in the region (Jaramillo-Legorreta et al. 2007).

The UGC and adjacent Colorado River Delta are known worldwide by their high fishing productivity. This region is home to commercial and non-commercial species as a spawning ground, nursery and reproduction area (Cudney and Turk 1998). As one of the most important ecosystems in...
the world, the area was declared a biosphere reserve in 1993 (DOF 1993; Figure 1). The reserve was created to protect species inhabiting the region that are commercially important, endemic or at risk of extinction. The area is supported by a management programme, which is designed to promote sustainable activities and maintain biodiversity of the reserve. The biosphere reserve is divided in two areas: the core zone where all activities are prohibited, and the buffer zone where fishing activities are allowed but with some restrictions on the use of gillnets (>15 cm) and fishing effort (SEMARNAT 1995). The most recent measure to protect the vaquita and its habitat of 1264 km² was a declaration in December 2005 of a vaquita refuge to further limit fishing activities and fishing effort to less than 160 vessels (DOF 2005). The refuge is divided into two sections, polygon A contained within the biosphere reserve and extending for 897 km², and polygon B outside the biosphere reserve that extends for 367 km².

The Bigeye Croaker, Micropogonias megalops (Gilbert 1890), is a coastal bottom-dwelling species (Varela-Romero and Grijalva-Chon 2004) with restricted distribution (Chao 1995) that is endemic to the Gulf of California (Castro-Aguirre 1978). The fishery became commercial in the UGC in 1991 as a socioeconomic alternative following the low capture rate of shrimp. This fish was first captured using larger vessels and, since 1992, small boats have accessed 15.46% of the production. The Bigeye Croaker fishery represents about 27% of fish species captured in the UGC. Based on catch volume and beached economic value, this fishery is one of the five most important in the UGC. Bigeye Croaker is caught from March to August, when it is abundant because this is the reproductive period, and capture conforms to economic and market necessities (Castro-González 2004). The high demand for Bigeye Croaker for the surimi industry in Korea has supported the fishery and reduced social problems caused by depletion of the traditional fishery-capture species (Cudney and Turk 1998). However, the lack of fishery regulations and fishermen knowledge of the law, over-fishing by commercial trawlers, Colorado River flows and illegal fishing is leading to declining catches and jeopardizing the permanency and stability of this fishery in the UGC (Galindo-Bect et al. 2002; Varela-Romero and Grijalva-Chon 2004).

This paper uses GIS to evaluate the economic value of the Bigeye Croaker fishery in the UGC biosphere reserve and in the recently created Vaquita Refuge Area. Also, the current situation in the commercial Bigeye Croaker fishery in the UGC was analysed through primary (interviews) and secondary (official catch reports) data that characterize basic variables, such as catch per unit effort (CPUE), total effort, catch fluctuations and fishing ground, for each community. Finally, we assess the sustainability of the current fishery and suggest management changes for its improvement.

Figure 1. Spatial distribution of the artisanal fishery within the Biosphere Reserve of the Upper Gulf of California (June 1993) and Vaquita Refuge Area (December 2005). (A) Core area; (B) Buffer zone in the Biosphere Reserve of the Upper Gulf of California; (C) Vaquita Refuge Area; (D) All fisheries area.
Methodology

From the three fishing communities in the UGC, 2554 catch reports by artisanal fishermen were compiled and analysed. Collected data, from 1995 through 2007, are from the official Federal Office records on fishing in the ports of SF, GSC and PP. Additional information was gathered from a closed survey based on direct interviews with 146 artisanal fishermen in these three ports. The questionnaires were designed to determine the direct costs of fishing operations, as well as information about fishing sites. The number of fishermen selected for interview followed the Cochran (1989) method:

\[
n = \frac{(Z^2 q / E^2 p)}{(1 + N [Z^2 q - 1 / E^2 p])},
\]

where: \( n = \) sample size, \( Z = CI = 95\% \), \( p \) and \( q = 0.5 \) equation distribution, \( E = 6\% \) precision, and \( N = \) size of the fisher community. The Greenberg method (1993) was used to randomly select fishermen from each port.

From the Bigeye Croaker landing records declared by fishermen to the local government fishery offices, information on capture site, weight of landings and landed price of the product was obtained. This information was subsequently used to identify fishing sites with the help of GIS and an economic evaluation of the fishery. Gross incomes were computed (disregarding investment costs) for each community, together with the associated costs of eliminating fishing activities within the Vaquita Refuge Area. The relationship between capture and fishing effort was analysed using simple correlation and linear regression.

Estimates of expanding and contracting periods of the fishery in UGC were analysed using the sustainable fishery index (SFI) (Ponce-Díaz et al. 2006):

\[
\text{SFI} = \ln(C_{X_i} / C_{\text{mean}}),
\]

where \( C_{X_i} = \) capture in \( i \) year, \( C_{\text{mean}} = \) capture mean for the total period.

Artisanal catches of Bigeye Croaker were represented spatially in GIS, identifying fishing sites within the Vaquita Refuge Area by using GPS records of fishermen for each journey (Figure 1). ArcView 3.2 and 2002 Conica Lambert software was used to download a projection map of the total Bigeye Croaker fishery and the community in the UGC. Fishing percentage within the Vaquita Refuge Area was obtained from the overall projected fishing sites. Catch percentages were computed by combining data on capture sites and fishing operations within the refuge, total operation costs (TOC) and gross income (GI). TOC considered operation costs (number of journeys by the small fleet in the region in year \( t \), fuel and food), equipment depreciation \( (ed) \) and annual inflation \( (at) \) (Banco de Mexico annual economic analysis), where:

\[
\text{TOC} = (t \times (\text{fuel + food}) + ed) \times at).
\]

The species-specific gross revenue (GR) in the local fishery was computed as:

\[
\text{GR} = \text{GI} - \text{TOC}.
\]

At the end of the questionnaire, fishermen were asked about alternatives to current fishing practices to reduce the impact on endangered species in the region. Some employment options are government-assisted. These data were used to understand the fishermen’s point of view about conservation of the endangered species and their interest, or lack thereof, in alternative jobs or activities in the UGC.

Results

Fishery analysis

Bigeye Croaker represents an important fishery for the UGC due to the high production volumes. The number of small boats officially registered in each community changed significantly during the study period (Figure 2A): PP had the largest number of small boats in 1996, followed by GSC and SF. In 2007, the fleet was 557 for GSC, 673 for PP and 840 for SF. By 2008, some small boats had been voluntarily retired through the ‘Programa de compensación económica para la Protección de la Vaquita en el Alto Golfo de California’ (economic compensation programme for the protection of the vaquita at the UGC), which began in December 2007. Figure 2B shows that as the number of boats increased, capture volumes increased accordingly. SF recorded peak catches in 1997 and 1998, with 1655 and 2018 t, respectively, GSC caught 1041 t in 1997, and PP 112 t in 2004. It is noteworthy, however, that the correlation between fishing effort and captures showed a negative tendency of \(-0.3696\) but was not statistically significant \((p = 2.14)\) because individual fishing was reduced during these years as the fleet size increased.

The CPUE showed two episodes in Bigeye Croaker capture. The first before 2000, with a high production of 2.1 t boat\(^{-1}\) year\(^{-1}\) for fishermen from GSC and SF, and a second, starting in 2001, with a general drastic decrease in production related to an increased effort to lower captures to 0.6 t boat\(^{-1}\) year\(^{-1}\) in all three communities. Clearly GSC and SF were the most important communities with the highest fishery over the course of this study. It is important to note that the PP community did not capture more than 1.0 t boat\(^{-1}\) year\(^{-1}\) during the period of analysis (Figure 2C). In general, the CPUE had a negative tendency with respect to total captures for SF, GSC and PP, and a correlation coefficient \((R^2)\) from 0.29 to 0.49.

Figure 3 shows that fishing effort in the three communities doubled through an increase in the number of small boats from 635 in 1995 to 1269 in 1997. In the following years, the small boat fleet increased slowly, until 2003, to 2070 boats. The number of small boats has since remained constant. Bigeye Croaker catches and CPUE exhibited comparable profiles,
with important peaks in 1995 (894 t), 1997 (2343 t) and 1998 (2868 t), with a CPUE for those years close to 3.7, 3.2 and 4.7 t boat\(^{-1}\) year\(^{-1}\), respectively (Figure 3). Since 1999, CPUE showed a reduction of 1.6 t boat\(^{-1}\) year\(^{-1}\), and fell to around 0.4 and 0.5 t boat\(^{-1}\) year\(^{-1}\) in 2006 and 2007, respectively.

Before 1997, the SFI identified Bigeye Croaker captures below mean production (1451 ± 696 t year\(^{-1}\)), but there was a production recovery from 1997 through 1999. Since then, production has declined despite a doubling of the number of small boats (Figure 4). From 2004 to 2007, a low recovery of the fishery was detected, with 1297 ± 379 t year\(^{-1}\); however the fishery maintained a low production below mean values. Bigeye Croaker production in SF had two distinctive stages, one from 1997 to 1999, with high-volume captures, reaching nearly 2100 t in 1998; and a second period (starting in 1999) with production under 800 t year\(^{-1}\). GSC had a smooth decline in production, one before 2000 with 885 t year\(^{-1}\) followed by 530 t year\(^{-1}\) after 2002. PP fishermen, in general, had low production, estimated at 74 t year\(^{-1}\).

The economic value of the Bigeye Croaker fishery from 1995 to 2007 is shown in Table 1. The mean value of catch during this period was approximately US$501,000 year\(^{-1}\). Operation costs of this artisanal fishery are relatively low, even considering the distance from the three ports to fishing sites. Bigeye Croaker from the marine protected areas generated an annual gross profit of US$ 388,000, with a return rate of 73% for each fishing season (capital cost depreciation not included).

### GIS Interpretation

The survey data and GIS analysis showed that six major fisheries are conducted within the Vaquita Refuge Area and in the biosphere reserve (Figure 1). About 84% of the total Bigeye Croaker catch in the UGC is in the marine protected areas, and 47% of the marine area of the biosphere reserve is used to catch this species (Figure 5). About 74% of the Bigeye Croaker artisanal catch is done in the biosphere reserve and 79% in the Vaquita Refuge Area. Fishermen from PP fish close to the Sonoran shoreline, with 80% of the catch inside the biosphere reserve and 79% in the Vaquita Refuge Area. Fishermen from GSC fish primarily inside the biosphere reserve and do not capture Bigeye Croaker in the Vaquita Refuge Area. Fishermen from SF fish near Baja California shoreline in the UGC, from the core zone to Puertecitos. About 75% of SF fishery is within the biosphere reserve and 70% in the Vaquita Refuge Area.
Gillnets used by fishermen are exceptionally large (≥ 200 m), with a mesh size of ≥ 10 cm².

**Social analysis**

A large number of fishermen would switch to ecotourism and storekeeping (45%). 9% would like to work in aquaculture and in the international manufacturing subcontracting industry, 22% would select an alternative fishery (mollusks, clams, oysters) or continue in the same fishery (Bigeye Croaker), and 17% would seek employment in artisan services (Table 2). By community, a significant number of fishermen in PP and SF would seek employment in the tourism sector (90%), and over 10% would continue in other fishing activities. In SF and GSC, more than 20% would seek employment as storekeepers, while more than 15% would not stop fishing for the species they currently capture. In PP and GSC, less than 8% would seek employment in the aquaculture sector, but no one would consider this option in SF. About 25% in GSC and more than 10% in PP and SF would seek employment in the construction trade.

**Discussion**

Marine protected areas are increasingly being used as a management tool to protect ecosystems, but there is some

---

Table 1. Catch, first-hand product value and operation cost from 1995 to 2007 for the Bigeye Croaker artisanal fishery of the Upper Gulf of California inside the Vaquita Refuge Area and the biosphere reserve. Value in thousands of US$.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch (metric tons)</td>
<td>894</td>
<td>1169</td>
<td>2343</td>
<td>2868</td>
<td>2012</td>
<td>1083</td>
<td>1110</td>
<td>907</td>
<td>1664</td>
<td>1320</td>
<td>912</td>
<td>938</td>
<td>1370</td>
<td></td>
</tr>
<tr>
<td>Value of catch</td>
<td>172</td>
<td>451</td>
<td>678</td>
<td>1167</td>
<td>751</td>
<td>343</td>
<td>367</td>
<td>219</td>
<td>328</td>
<td>660</td>
<td>438</td>
<td>408</td>
<td>528</td>
<td>501</td>
</tr>
<tr>
<td>Costs of catch</td>
<td>24</td>
<td>50</td>
<td>69</td>
<td>82</td>
<td>101</td>
<td>115</td>
<td>127</td>
<td>133</td>
<td>141</td>
<td>148</td>
<td>153</td>
<td>159</td>
<td>165</td>
<td>113</td>
</tr>
<tr>
<td>Gross profit</td>
<td>148</td>
<td>401</td>
<td>609</td>
<td>1085</td>
<td>650</td>
<td>227</td>
<td>240</td>
<td>86</td>
<td>187</td>
<td>512</td>
<td>285</td>
<td>249</td>
<td>363</td>
<td>388</td>
</tr>
<tr>
<td>Return rate (%)</td>
<td>86</td>
<td>89</td>
<td>90</td>
<td>93</td>
<td>87</td>
<td>66</td>
<td>65</td>
<td>40</td>
<td>57</td>
<td>78</td>
<td>65</td>
<td>61</td>
<td>69</td>
<td>73</td>
</tr>
</tbody>
</table>

Source: Government Fishery Offices in the communities of the UGC.
debate as to whether they should be used to protect and increase biodiversity as a fisheries management tool or should serve both purposes (Monaco et al. 2007). Regardless of the objectives for implementing a marine protected area, high effort within the marine reserve may limit the potential of fishing and increase the abundance of Bigeye Croaker populations (Sladek Nowlis and Friedlander 2004). Our analysis showed that the UGC Biosphere Reserve and the recently declared Vaquita Refuge Area are very important for artisanal fishing (Lunn and Dearden 2006), where Bigeye Croaker, even at low CPUE, generates important income for artisanal fishermen. These findings represent important challenges to the fulfillment of goals for the recovery of endangered and commercial species of the biosphere reserve and the Vaquita Refuge Area. Moreover, the number of small boats who reported their captures to the federal fishing office in 2005 in each community is greater than that recommended for the Vaquita Refuge and was more than the number registered in the RNP (Fisheries National Register).

To a great extent, operating costs determine where fishing is conducted in the UGC, in particular in relation to the distance of fishing sites from ports, and where depths range between 7.3 and 36.6 m in the southern boundary of the core area to the southern limits of the biosphere reserve, where most of the Bigeye Croaker fishery is performed (Cudney and Turk 1998). The fishing season for this resource interferes with spawning migration of adult totoaba in the core zone area (Cisneros-Mata et al. 1995) where fishermen are not allowed to fish (DOF 1993). The Vaquita Refuge Area was highly impacted by fishermen of SF, who fish within this refuge because of their proximity to it, and as soon as the shrimp season closes the Bigeye Croaker season starts (Cudney and Turk 1998).

Although the Bigeye Croaker capture in the marine protected areas continues at a level of production that is very important, which makes it attractive to the fishermen, the volume captures and CPUE tend to be negative. The addition of new fishermen to the area will not enhance fishermen’s welfare, and the fishery will become unsustainable in a relatively short period of time (Ponce-Díaz et al. 2006). Moreover, the 2070 small fishing boats working in the UGC could be a threat to the vaquita because gillnets are used during the Bigeye Croaker season, jeopardizing the vaquita reproductive season (D’Agrosa et al. 1995; Rojas-Bracho et al. 2006).

A large number of fishermen will continue fishing in the marine protected areas even when closure is decreed. Job alternatives promoted in the area must consider the fishing culture and people’s knowledge of other potential activities (PACE 2008). Even though tourism is accepted as an alternative by 33% of the fishermen, 23% of those interviewed would not stop fishing because it is the only activity they feel comfortable with and they have fished for many years. It has been suggested that the fishery in the UGC should be closed, but this measure, instead of promoting vaquita recovery, would only encourage illegal fishing, jeopardizing all vulnerable species in the area. Given the potential conflict, value of endangered species and impact to the environment, enforcement of fish management practices will probably allow a specific number of fishermen and specific fishing tools to be used to fish within the biosphere reserve and the Vaquita Refuge Area by providing equipment and techniques that would not further endanger the threatened species. Fishermen in the region have agreed to set up fishing restrictions, both in specific fishing areas and for specific time periods (Castro-González 2004). This would help in recovery of the Bigeye Croaker population and protection of endangered species. Bigeye Croaker production requires adaptive strategies to provide appropriate management and conservation of this ecosystem (Palumbi et al. 2003), as well as enforcement of the marine protected areas legislation. The success of most fisheries management policies to conserve species depends on the vulnerability of the species and size of the protected area (Carter 2003; Clark et al. 2005). Unfortunately, the study area has a well-established fishing tradition; enforcing a permanently closed season could produce severe social disturbance.

We believe that a practical policy of management of the Bigeye Croaker fishery in the marine protected areas is needed to avoid the perception that such areas are only for biodiversity conservation, and policies must address inconsistencies between conservation and fisheries approaches for the regional management of natural resources. An important aspect to ensure the efficiency of marine protected areas in the UGC is the need to provide those who depend on harvesting natural resources with viable alternative livelihood options. Developing and promoting capacity building among both government personnel and local stakeholders is a further major requirement. Another aspect highlighted in this paper was the need to generate knowledge to serve management needs and enable implementation of ecological, social and economic monitoring and evaluation programmes. For this, the contribution of science is vital, and collaboration between local resource users, the government and academia must be reinforced.

### Table 2. Alternative activities chosen by fishermen if they quit fishing (percentage).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Puerto Peñasco</th>
<th>El Golfo de Santa Clara</th>
<th>San Felipe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tourism</td>
<td>29</td>
<td>17</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Will not stop fishing</td>
<td>3</td>
<td>17</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Other fishing activities</td>
<td>14</td>
<td>2</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Work at other enterprises</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Storekeeper</td>
<td>7</td>
<td>27</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Other (Trade)</td>
<td>14</td>
<td>254</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Do not know</td>
<td>21</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: Survey based on direct interviews with artisanal fishermen in San Felipe, B.C., Golfo de Santa Clara and Puerto Peñasco, Sonora.
The greatest and most urgent challenges are increasing inter- (municipal, state, federal) and intra- (sector) institutional coordination towards the development of an integrated coastal management policy that has an adequate legal framework and embraces long-term objectives. Simultaneously, it is crucial to implement effective and equitable participatory decision-making mechanisms to proactively involve local stakeholders in every stage related to the design, implementation and management of protected areas.

Acknowledgements

Financial support was provided by CONACYT Grant 48445. GRQ received doctoral studies grants CONACYT 112401 and COTEPABE-IPN 347. We thank the Editor for his comments on an earlier draft of the manuscript.

References


