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Offshore Aquaculture Economic Modelling and Site Selection Protocols

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OFFSHORE AQUACULTURE ECONOMIC MODELING AND SITE SELECTION PROTOCOLS

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The offshore marine aquaculture industry has shown slower growth than other regions and sectors of the industry despite ample spatial opportunities. A primary cause for this is the nature and perception of aquaculture investment opportunities which are less attractive relative to alternatives in the tropical regions of the Americas.

Two consulting tools were built to facilitate the progression of potential projects beyond the planning stage. An economic model projects capital costs and cash flows based on industry supported fish performance and market assumptions which gives an early indication of the financial viability of a proposal. Remote site selection protocols use GIS software to analyze the availability and quality of potential sites within an area of interest. These tools form the basis of early stage consulting and serve as support or opposition to a proposal before significant time and resources are spent. By creating using models which have been successful in projecting costs and revenue for other companies as well as finding grow out locations which agree with industry progress to date, uncertainty is reduced from investment proposal and they appear to have less risk.

An example is modeled for each tool. The economic model finds an offshore farm growing snapper and cobia to be an attractive investment with an IRR of 36% over 10 years. The remote site selection protocols identified 29.9 thousand km^2 of suitable ocean of offshore aquaculture of cobia in the Gulf of Mexico, Caribbean Sea and the Bahamas

with the highest ranked sites on the Caribbean coast of Costa Rica and Panama. Both tools produced results consistent with what is observed in the industry.

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AVHRR – Advanced Very High Resolution Radiometer. A satellite sensor used by NOAA to measure reflectance.

ESRI – Environmental Systems Research Institute. A leading supplier of GIS software and technology.

FAO – Food and Agriculture Organization. A branch of the United Nations.

FCR – Feed Conversion Ratio. The ratio between feed used and product harvested.

GIS – Geographic Information Systems.

IDW – Inverse Distance Weighted. A technique to interpolate point data into rasters.

IRR – Internal Rate of Return. A measure of the returns of an investment relative to the input.

NASA - National Aeronautics and Space Administration. The United States government agency responsible for their space program.

NHC – National Hurricane Center. A branch of NOAA

NOAA – National Oceanographic and Atmospheric Administration. An agency within the United States department of Commerce.

NODC – National Oceanographic Data Center. One of the national environmental data centers operated by NOAA.

NPV – Net Present Value. An estimation of the current value of an investment accounting for the discounted value of future earnings.

PPT – Parts Per Thousand.

SGR – Standard Growth Rate. Growth rate measured as a percent of body mass.

SST – Sea Surface Temperature.

UMEH – University of Miami Experimental Hatchery.

Chapter I

Introduction

The global aquaculture industry has grown by an average of 6.1% annually between 2000 and 2011 (FAO 2013) but this growth has not been evenly distributed among all the different sectors of aquaculture. Fresh water and brackish water aquaculture has shown annual growth of 6.8% over the same time span while marine aquaculture has shown annual growth of 5.5% with even less growth in recent years; 4.9% between 2005 and 2011 (FAO 2013). Marine aquaculture accounts for 46.9% of total aquaculture production despite much greater opportunities for production and growth (Jeffs 2013).

Marine aquaculture production in the tropical regions of the Americas has also seen limited growth (figure 1; data from FAO 2013; Posadas and Bridger 2004) and has

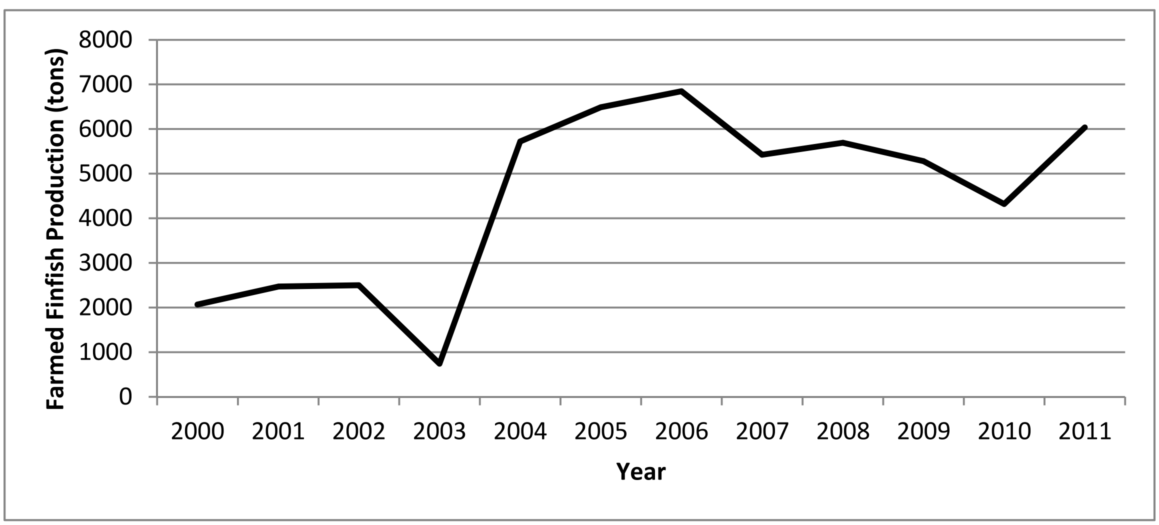

Figure 1: Marine finfish production from Aquaculture in countries between the Tropic Cancer and the Tropic of Capricorn in the Americas. USA, Brazil, Mexico and The Bahamas are included but Chile and Peru as well as all salmonid culture are excluded.

been almost stagnant in recent years. Since 2004, aquaculture production in these regions has shown 5% total growth, increasing from 5,721 to 6,037 tonnes in 2011. This accounts for less than 1 percent of total global aquaculture production. Kapetsky *et al.* (2013) analyzed the areas of ocean with appropriate depths, currents and temperatures for Atlantic salmon (*Salmo salar*; a temperate species) and cobia (*Rachycentron canadum*; a tropical species) while also considering economic restrictions such as distance to shore (25 nautical miles was used as the limit). They found that there is 97 192 km^2 of ocean which could potentially support tropical offshore aquaculture compared to 2 447 km^2 for temperate offshore aquaculture. This is a 40-fold increase in site availability for tropical over temperate aquaculture which demonstrates the large potential for growth in the tropical offshore sector of the aquaculture industry, yet begs the question as to why it is not expanding faster.

Despite the substantial opportunity for growth, offshore aquaculture, as mentioned, has not developed at expected rates nor will it develop as an industry unless it is viewed as an attractive investment. The product of offshore finfish aquaculture, edible fish products, is in direct competition with wild fisheries and inshore aquaculture, both of which tend to require lower capital costs to enter the industry as well as lower production costs per kilogram produced (Knapp 2013). If these two alternative sources of seafood can sustainably supply enough fish to keep the price low, then offshore aquaculture will never develop. Knapp (2013) highlights three primary drivers which are likely to make offshore aquaculture increasingly profitable in the future. Offshore aquaculture is a relatively new industry and advancements in offshore production technology may reduce both capital and operational costs. The Norwegian salmon industry, for example, has increased production from 130 000 tonnes in 1992 to over 650 000 tonnes in 1995 while showing almost no change in direct employment (Knapp 2013). This caused employment per thousand tonnes produced to drop from 25 to just 5 jobs over this span. This is a result of improved technology and management techniques. A similar improvement in human resource efficiency, and likely feed usage and other resource as well, use can be expected as the offshore aquaculture industry matures. Offshore aquaculture also has the biological and economic advantages of a better grow-out environment which may improve fish performance as well as a greater opportunity to take advantage of economies of scale. Offshore aquaculture may not be at as large a disadvantage economically once the industry matures. There are many pilot and commercial scale farms already operating in the tropics and sub-tropics of the Americas developing these technologies. The Cape Eleuthera Institute in The Bahamas has a submerged Seastation 3000 which is part of their aquaculture research program aimed at improving offshore aquaculture viability in tropical regions. Their submerged cage survived hurricane Frances (2004), Irene (2011), and Sandy (2012; Geoff Walton, personal communication; Benetti 2004), and has been outfitted with a newly developed Predator-X netting designed to resist damage caused by sharks (Roberson 2012; Sclodnick *et al.* 2011). Earth Ocean Farms, Open Blue, Blue Ocean Mariculture, and Martec Mariculture are other companies which are developing and demonstrating offshore aquaculture technologies and practices and work with the University of Miami Experimental Hatchery (UMEH). A focus on cage technology, especially remote monitoring and operational equipment, as well as hatchery technology and feed formulations for fish which are in demand in these regions have been established as primary technological concerns (Browdy and Hargreaves 2009).

The second driver outlined by Knapp (2013) is demand for seafood which is expected to grow both as a function of global population growth as well as increasing per capita income in developing countries, particularly China, India, and South Pacific nations (World Bank 2013). Increased income is often associated with an increase in protein consumed and fish consumption in particular. Gross domestic product is estimated to increase by 17.4% by 2030 driven primarily by a projected 177% increase in China, a 92% increase in India and an 88.4% increase in South Pacific nations (World Bank 2013). The three regions are projected to have the highest increase in per capita seafood consumption at 1.2, 0.8, and 1.8% respectively. The World Bank (2013) also projects an increase in world population by 20.2% which further increases demand. This will create a projected deficit of 32,291,000 tons (27.0%) of seafood in 2030 from 2010 production levels (World Bank 2013). Demand may be further increased through improved awareness of the health benefits of eating seafood as well as increased availability as remote locations far from oceans are now regularly receiving sea food.

The last driver is a potential reduction or stagnation in supply from alternative sources or the inability of wild fisheries and inshore aquaculture to grow their production. Global catches of wild fish have remained fairly constant since the 1980's (Brown 2011; FAO 2013; FAO 2009) but with the human population growing, the available wild catch per person has dropped from a high of 17.2 kg per person per year to 13.3 kg in 2008 (Brown 2011; FAO 2013). Capture fisheries have overexploited many fish stocks, and have turned to different species to make up the deficit. The result of this has led to 32% of fish stocks being overexploited, depleted or recovering in 2008, increasing from 10% in 1974 (FAO 2013). An additional 53% of fish stocks are fully exploited making them unable to produce more than are currently harvested. Inshore or near-shore aquaculture still has potential to increase production (Kapetsky *et al.* 2013) but this is limited by the available areas which are suitable for “near shore style” aquaculture (protected waters close to shore) as well as competing human uses for these areas and environmental factors which make them unsuitable (eg. hurricanes).

Given the available spatial and economic opportunities for growth in this sector of the industry, the barriers to development must be examined. These barriers fall into two categories which are directly linked to each other; reasons not to support the industry and reasons not to join the industry. Support of the industry would include the creation of legislation to facilitate the siting and operation of aquaculture farms, as well as the research, development, and commercialization of feeds and technologies which are required to run an offshore farm. Feeds and cage technologies are already commercially available but most of what is used in tropical aquaculture in the Western hemisphere is either not optimized for its application (many farms use generic marine fish feeds instead of species specific or age-class specific feeds), or is not being produced on a large enough scale to reduce the price to manageable levels. Submersible cages are required to grow fish in regions with hurricanes but often cost three to six times more than the floating cages used in calmer coastal waters. This cost will drop when demand for cages increases and the companies can take advantage of economies of scale. All of these barriers are being addressed, but there would be stronger incentives to develop these products and policies if there was a larger industry to support.

There are three major economic barriers to joining the offshore industry; the investment in a new business is less attractive than alternative investment options, there are few examples of successful farms to provide a standard for success and confidence in the concepts, and lastly, there is a lack of both expertise and general awareness in the field among the investing community. Other barriers to offshore aquaculture expansion exist but the focus of the current study is limited to economic factors. The attractiveness of offshore aquaculture as a business venture is likely to improve over time (Knapp 2013). As outlined above, the development of better feeds, automated technologies, and infrastructure to produce aquaculture equipment will lower the capital required to start a farm and increase the potential profit margins. The other two barriers to joining the industry are intrinsic to any new emerging industry so the development of successful examples and increased awareness must wait until enough investors start aquaculture facilities without these assurances (Hoagland *et al.* 2005). Making a comprehensive and dynamic economic model as well as site selection protocols available will provide key preliminary information to encourage investment in aquaculture (Engle 2010). With the lack of other farms in the region to provide examples, whole farm economic models are the best tools to provide confidence in a business plan (Knapp 2013; Engle 2010; Hoagland *et al.* 2005). This will also help to “bridge the gap” in information between industry professionals and interested investors.

Other studies have used various definitions for “offshore aquaculture”. Drumm’s (2010) definition is suitable for the current study and has been used by other authors (Kapetsky *et al*. 2013). Drumm (2010) defines “offshore aquaculture” as “taking place in the open sea with significant exposure to wind and wave action, and where there is a requirement for equipment and servicing vessels to survive and operate in severe sea conditions from time to time. The issue of distance from the coast or from a safe harbour or shore base is often but not always a factor". Since the current piece is not a comparative study, there is no need to define offshore versus other types of aquaculture. The site selection model will only define sites in terms of degree of suitability for grow-out although the criteria used in the selection are appropriate for "offshore grow-out".

Chapter II

Economic Models

<u>The Role of Economic Models in Offshore Aquaculture:</u>

Economic modeling is a valuable tool for aquaculture and should be included in all early stage feasibility studies (Engle 2010; Hoagland *et al*. 2005). Modeling is more applicable to offshore aquaculture farming than other industries for four primary reasons. The first is that offshore aquaculture is a new and quickly changing industry which makes models, and not empirical example, a more appropriate means to predict future viability of farms (Knapp 2013; Lovatelli *et al*. 2013; Hoagland *et al.* 2005). As the industry develops and more examples of successful and unsuccessful farms become available, empirical analysis will become cheaper and easier. Until then, modeling is essential to gain insights on the risks and opportunities in the industry (Knapp 2013; Engle 2010). Secondly, aquaculture operations require specialized knowledge which is not widely understood among many investors. This is most pertinent to the relative importance of feed in the operating costs and how feed is converted into saleable product. Effective models need to be built by parties with experience and exposure to fully operating farms and with insight into their operations. Third, modeling allows investors entering the industry to look at how to optimize their profits (Knapp 2013; Engle 2010; Hoagland *et al.* 2005). The size of the farm is a key factor to consider and represents a tradeoff between increased capital investment and decreased cost per unit production. Models allow this tradeoff to be investigated and optimized for each investor's needs. Fourth is the need for sensitivity analysis in a dynamic and developing industry. Changes in key assumptions about the costs of feed, the price of product or the growth parameters can have dramatic effects on profitability (Knapp 2013; Nobel *et al.* 2012; Engle 2010; Hoagland *et al.* 2005; Posadas and Bridger 2004). In an industry that is growing and developing as quickly as offshore aquaculture is, understanding the effect of changes in these assumptions is crucial in evaluating a business plan. Models need not only accurate assumptions of parameters but also accurate assessments of the uncertainty in these assumptions and a means to test them (Knapp 2013; Hoagland *et al.* 2005).

The model is designed to be a dynamic document which can have input values changed to suit the needs of a client. The need for a dynamic document is essential for a new business scenario and allows the accuracy of the model to be improved as real values can be substituted for assumptions.

The model can be applied to any finfish species grown in cage. Many elements of it could be applied to other forms of aquaculture but the differences in the relative importance of some variables make it preferable to model these systems differently (Kankainen *et al*. 2012). For example, profit in recirculating aquaculture systems is significantly affected by energy costs so energy usage would need to be modeled as a function of production in order to produce accurate output. The proposed model has energy costs as a simplified single line item which would be insufficient detail for recirculating systems. Production in pond culture systems is significantly affected by ambient temperature which varies seasonally. Temperature is less varied in an open ocean grow-out so is not covered in the model.

Many companies or investors will build their own models or look for existing models on which to base their assessment of offshore aquaculture as a potential investment. Such models are available for various species, scales and culture methods

(Noble *et al.* 2012; Hoagland *et al.* 2005; Miao *et al.* 2009; Cacho 1993; Leung, *et al.* 1993; Talpaz and Tsur 1982; Sylvia and Anderson 1993) but rarely are they available as dynamic documents which allow the substitution of newly researched values for old assumptions as well as the testing of uncertainty. Most models also do not incorporate the holistic view of starting an aquaculture operation from scratch and omit certain costs which can be significant, such as the initial investment in infrastructure, and the time required to reach full production. Having detailed, dynamic, and testable models available publicly or commercially would benefit aquaculture managers who are not at full production capacity, particularly those who have yet to invest in infrastructure.

This model is intended to be used as a consulting tool to produce initial estimates of cash flow before major investments are made, and providing continued information on optimal farm operations. It was built in Excel and is intended to exist as a dynamic document which is continually consulted and edited as the consulting and early development of the project progress. In this way, the model transitions from generic to specific as assumptions and industry standard values are replaced with researched values applicable to the specific project at hand. This is in contrast to static models which are produced as hard copies and have the usefulness of the models in the results as opposed to the formulas. This also allows it to be reusable while static models become out dated or apply only to the specific situation which the inputs describe.

Details of the Model:

The model projects expenditures and revenue over a 10 year period. For competitive investments, this timeframe is long enough to capture the investment period, breakeven point and several years of profitable operation, while not allowing too much uncertainty by predicting events too far in the future. Two species are included which can be modeled as growing simultaneously or alternatively. Cobia (*Rachycentron canadum*) and red snapper (*Lutjanus campechanus*) were selected as examples to use in the model due to their commercial feasibility level, and the accessibility of reliable values for the biological and market performance parameters in real aquaculture settings. Any species which can be grown in off shore or near shore condition could be substituted for these species and modeled with accuracy as long as decent assumptions for their performance can be produced.

Each element of the model is described in the order in which they appear. Details of each cell are described in the most appropriate section. The cover page, for example, lists a summary of key statistics which are linked to other places in the workbook. The calculation of these statistics is described in the section which contains the cells included in those calculations, and not in the cover page's description. Many values are estimated based on observed values seen in the tropical regions of the Americas. The following organizations have contributed values to the model; UMEH, Martec Mariculture, Open Blue Seafarms, Blue Ocean Mariculture and Earth Ocean Farms (Benetti, 2013).

The cover page is designed to give a brief summary of key numbers in a simple layout. A title is included with room to insert a company logo, and a table of contents, each item of which is hyperlinked to its respective worksheet. Three boxes (figure 2) make up a summary of key parameters. The first box summarizes annual values at full scale production and includes the following values for both species included in the model; cost per fingerling, cost per kg feed, feed conversion ratio (FCR), stocking density, total production in kg, and market price. These parameters are linked from other areas of the workbook and show the values as calculated in the final year so as to represent full scale production. The parameters variable cost per cage, revenue per cage, gross profit per cage, variable costs, revenue and gross profit are also included as species specific annual values which are linked from other locations in the workbook. The variable cost per cage,

Summary of Key Numbers (annually for full stocking of each species)		
Parameter	Cobia	Red Snapper
Cost per Fingerling	$0.317	$0.373
Cost per Kg Feed	$1.80	$1.80
FCR	1.8	2.0
Stocking Density	23	20
Total Production (kg whole)	1,324,800	1,104,000
Market Price $/lb	$6.50	$5.25
Variable Costs / Cage	$502,715	$480,498
Revenue / Cage	$1,118,499	$851,865
Gross Profit / Cage	$615,784	$371,367
Variable Costs	$6,032,581	$5,765,980
Revenue	$13,421,988	$10,222,382
Gross Profit	$6,922,799	$4,456,402
Total Variable Costs	$11,798,561	
Total Revenue	$23,644,370	
Gross Profit w/o Labour	$13,536,510	
Gross Profit	$11,845,809	

Start up Costs	
Year 1 Costs	$3,241,734
Out-of-Pocket Investment	$8,428,539
Break Even Year	4

Ten year Total			
Total Invested in Capital	$17,993,731		
Total Invested	$93,259,036		
Total Revenue	$138,757,280		
Total Profit	$45,498,244		
IRR	37%		
Net Present Value	Rate:	10%	$18,466,429

Figure 2: Three boxes shown on the title page of the economic model.

revenue per cage and gross profit per cage take total values from year 10 and divide it by the total number of cages for year 10 which allows those value to change when the total cage number is changed. Total variable costs, total revenue, gross profit without labour, and gross profit are then shown for year 10 values for both species combined to reflect the whole farm values.

The second box summarizes the early stages of the investment. Year 1 costs is the sum of all expenditures in year 1 as no revenue is expected. Out-of-pocket investment is calculated as a sum of "If" statements where each years' net profit is added to the total if it is in fact a net loss. Otherwise zero is added to the total. The formula is written as follows:

$$=-1*(P_1+IF(P_2<0,P_2,0)+ IF(P_3<0,P_3,0)\ldots IF(P_{10}<0,P_{10},0))$$

The initial negative 1 multiplier changes the negative into a positive value. P_1 is the sum of the net profit for species 1 and species 2 in year 1. It will always be a loss so is always included. The second term of the equation may or may not represent out of pocket costs if revenue in year 2 is greater than the costs that year. The IF statement syntax take a condition, in this case profit in year 2 (P_2) is less than zero, and returns the value after the comma if the condition is true, and the third value of it is false. Therefore, the term will add the value of the loss in year two (expressed as P_2) to the total only if that cell is negative. Otherwise, it will add zero so the value does not change. As such, the equation will only add the net losses to the total up to the point of the farm reaching profitability, at which point the company can run on revenue and will no longer need outside investments. The next value in box 2 is the break-even year. This value is calculated with a similar formula to the out-of-pocket investment except instead of adding the value of the cell itself, it adds 1. The formula starts at 2 representing year 1 plus the fact that the break even points would be the following year, and then adds 1 for each successive year which shows a net loss.

The third box characterizes the cumulative 10 year investment. The 10 year total values are given for total investment in capital, total dollars invested, total revenue, total profit, internal rate of return (IRR) and net present value (NPV). The total dollars invested in capital is the summation of capital costs from the 'Capital Costs' worksheet. Some of these costs occur after revenue is being generated so this value does not reflect the out of pocket cost or the initial year-1 investment as was calculated above. Total invested is the cumulative capital costs and operating costs for both species for all 10 years. Total revenue and total profit are calculated the same way but for their respective values. IRR is calculated using Excel's IRR function, as is NPV using the yearly profit and a user inputted discounting rate (10% is used).

The 'Capital Costs' worksheet contains an itemized list of each one-time expenditure for each year. The list is broken down in to three sections, one for the hatchery, one for the grow-out site, and one for an office. A given company may have multiple hatcheries or opt to buy their seed stock from an independent supplier. Also the design of hatcheries as well as grow-out sites and business offices vary dramatically so the specific line items included reflect a generic farm of a similar style to those which exist in the tropical regions of the Americas. This page will need to be modified when applied to a real consulting situation but serves nicely for the demonstration of the model. The value of items listed need to reflect the cost of purchasing the items as well as transportation, installation, and any taxes associated with the purchase or transport. These associated costs can be sizable and vary between countries and locations. The values are estimates and are of a comparable range to those seen at other offshore farms in tropical regions of the Americas. The last line item in each section is labeled as "Equipment repair/replace" and is calculated as 8% of the value of all the capital owned up to that year. The repair/replace rate of 8% was arrived at through the estimation that many items will last around 10 years (giving a discounting rate of 10%; items include hatchery equipment such as tanks, pumps, and blowers) but the large line items can last up to 20 years (giving a discounting rate of 5%). The hatchery building, Aquapod cages, mooring grid, and pier should all have a life span approaching or exceeding 20 years (with regular repairs) and account for almost $9,00,000 of the capital costs which is over half of the total investment in capital, but the discounting rate was conservatively set for all items at 8%. This simplifies the calculations for repair/replacement costs which is a small line item. The large items are account for as paid up front and not amortized although the accounting can be done in that style as well. The value of the larval rearing tanks, and grow-out cages are calculated as a function of production level and grow-out volume. All other items are unlinked. The delay in purchase of the cages allows the managers to project when the cages will be needed and can modify this if these projections change. Delaying the purchase of large line items such as these can improve the IRR and NPV (Engle 2010; Hoagland *et al*. 2005).

Salaries are summarized in the ‘Payroll’ work sheet. These do not include employees working in the hatchery which are included in the ‘Hatchery Running Costs’ worksheet. This facilitates the assessment of the cost per fingerling and comparisons to competing companies or alternative sources of fingerlings. Cost per position is calculated as a base salary plus 8% of the base salary as insurance, and 25% of the base salary as fringe costs. The fringe cost accounts for non-salary expenses which can vary in nature by position. For management positions this includes bonuses, cell phones, living or travel stipends, conference fees, and business/networking expenses. For non-managerial positions this would include transportation, meals, company clothing, and other small expenses. The base salary and relative values of insurance and fringe costs were estimated based on those observed at other offshore aquaculture farms in the tropical regions of the Americas. Both insurance rate and non-salary compensation will vary by country and region.

Seed stock (source of larvae or fingerlings) is a highly variable cost. Some companies consider a reliable source of fingerlings to be the driver of an operation and build their own hatchery, while others see the grow-out as the phase where profit is generated and outsource their fingerling production. Building a hatchery requires a lot more capital investment and managerial involvement but reduces the risk of having empty or understocked cages in the ocean for extended periods. Either option could be preferable depending on available capital and the quality, cost, and reliability of alternative sources of fingerlings. The model accommodates this by modeling the hatchery expenditures, including labour, separately. The cost per fingerling is then calculated and this value is put into the species production worksheets. By replacing the calculated cost per fingerling values with a price from a hatchery (and removing the hatchery capital cost) the model switches from internal seed stock to external seed stock production.

The 'Hatchery Running Costs' worksheet itemizes the major recurring costs for a generic marine hatchery. The costs associated with larval rearing are calculated as the unit cost multiplied by the units used per tank multiplied by the total number of larvae required that year divided by the larvae produced per tank. The equation is as follows where C is the unit cost, T is the units per larval rearing tank, F_{Cobia} and $F_{Snapper}$ are fingerlings needed at cage stocking and L is the larvae produced per tank.

$$=T*C*((F_{Cobia}+F_{Snapper})/L)$$

The larval production per tank and resource usage is estimated based on the average production at UMEH in 12 tonne tanks (Benetti *et al*. 2008a; Benetti *et al*. 2008b) and confirmed with literature sources (Holt *et al.* 2007). Expenses which are not directly proportional to production levels have been estimated based on information from hatcheries around the Americas which are of a comparable production capacity to the example used in the model. Hatchery labour is included in this worksheet and is also estimated based on information from North and South American hatcheries of a comparable size. The items are totaled by year as well as by month which is often an easier metric to compare between hatcheries. The cost per fingerling is calculated for each species. Cobia cost per fingerling is calculated as the total hatchery costs divided by the number of larvae produced that year multiplied by the ratio of cobia produced to total larvae produced that year. The same is done for snapper.

The species grow-out economics worksheets take the values from the previous three sheets and compute the revenue, costs, profit, IRR, NPV, and breakeven point for each species. Three identical worksheets are included in the workbook, two for the species being modeled (in this case cobia and red snapper) and an extra labeled ‘Blank Worksheet’ which allows users to experiment with values without modifying their researched values from the other sheets. Additional grow-out economic sheets can be added to model more species but most farms only grow one or two species. Two species is the simplest number to demonstrate this aspect of the model. Modeling multiple species can highlight the economic benefits or drawbacks of each but usually one species emerges as the most profitable and a farm's value is maximized by allocating all of its grow-out volume to this species. Farming a second species can provide advantages through product diversification which can allow access to different markets and market security in the dynamic seafood market.

For each parameter, the model can take a unique value for each of the 10 years it covers. The first parameter is the cages which are separated into three categories according to size. The Aquapod was selected as the cage design in this case due to its resistance to hurricane damage and shark attacks, both major concerns in warm water mariculture (Roberson 2012; Sclodnick *et al.* 2011; Benetti 2004). There are three sizes of Aquapods which can be used for commercial scale aquaculture, the A1660, the A3600, and the A4800. The model names refer to the internal volume in cubic meters. The addition of cages must agree with the capacity of a typical mooring grid (typically 10 or 12 cells) as well as the construction ability of the cage company (approximately two weeks per cage; personal experience). It is also preferable to avoid empty cages sitting in the water, so the cage capacity should only be increased once the fingerling production capacity is anticipated to fill that volume. The number of cages in each year is multiplied by the respective volume of each model to give a total volume of all cages. The next two rows ask for stocking density in kg per m^3 and harvest size as manual inputs, which along with total cage volume are used to calculate total number of fish at harvest. The next row takes a manual input of survival rate, which is used to calculate the required fingerlings needed to stock the cage to achieve the desired stocking density at harvest. The initial stocking density in fingerlings per m^3 is then calculated for reference (this is not used in further calculations but some managers use this as a metric). The next line is a manual input of month per cycle (the number of months the fish must be in the grow-out environment to reach market size) which is the last input needed to calculate total mass of fish produced. The total fish mass is per year and is calculated as using the following formula

$$=S*N*(12/T)$$

where S is harvest size in kg, N is total fish at harvest and T is the months per cycle. This formula accounts for the varying grow-out times for different species. Cobia, for example, requires 12 month of grow-out time to reach market size (depending on feed, environmental conditions, target harvest size, and other variables) so the 12/T term becomes 1 cycle per year. For a fish that takes 6 months to reach harvest size, this term would equal 2 since two sets of fish reach harvest size in each cage per year. This was deemed the best way to model the effect of staggered cage stocking. Although a given year may have 4 cages stocked in that year, the fish will not be stocked at the same time, but are staggered to allow for continual harvesting as each cage successively reaches harvest size. As such there is a slight disconnect between when the model claims fish will be produced, and therefor revenue received, and when these events will actually take place.

The next two rows take percent yield and market price and manual inputs. These need to be researched and must both refer to the same product (fillets versus head on gutted for example). The market price can be put in as either dollars per pound or per kilogram. There is drop down menu in the row's header to specify which is being used.

The annual sales is the last row in the “revenue” half of the worksheet. It calculates revenue as total mass of fish per year multiplied by percent yield multiplied by market price. If market price is expressed in pounds, this value is multiplied by 2.20462. This condition is reflected in the equation which is written as:

=IF(MU="Market Price $/kg",((H*Y*P)),((H*Y*2.20462*P)))

where MU is the market price unit specification, H is total harvested mass, Y is the percent yield and P is the market price. Considering the IF statement syntax, the formula will consider if the market price units is in dollars per kg or dollars per pound. If the first statement is true and the market unit cell reads "Market Price $/kg", then the formula will give the second term of harvest mass multiplied by percent yield multiplied by market prices. Otherwise it will give the third term which is the same formula multiplied by the kilograms to pounds conversion factors of 2.20462.

The “costs” half of the worksheet starts with the cost of per fingerling. This value is linked to the corresponding year and species from the ‘Hatchery Running Costs’ worksheet, but can be replaced with manually inputted values to simulate buying fingerlings from an external source. In the example, the first two years have values inputted manual to anticipate the time it takes for a hatchery to start producing fingerlings while the remaining years are linked to the calculated value from the hatchery worksheet. The cost of fingerlings is the next row and calculated as the cost per fingerling multiplied by fish at stocking. The FCR and cost per kg of feed are the next two rows and both are manually inputted from researched values. The FCR is an economic conversion which must account for both the biological conversion of ingested feed plus the wasted feed (falls through cage, etc.). The economic FCR is the total amount of feed purchased divided by the total mass of fish harvested. These two values are multiplied together and the product is multiplied by the total mass of fish produced to get the total cost of feed per year. Processing, packing, and shipping costs are combined into one cost which is calculated as the total harvested mass in that year multiplied by a manually inputted processing cost in dollars per pound or dollars per kilogram. A dropdown menu beside the processing cost allows for the user to specify the units on the processing cost based on how they are quoted. The cost of processing, packing and shipping reflects this option in its calculation which is as follows:

```
=IF(PU="$/lbs",H*PC*2.20462,H*PC)
```

where PU is the processing cost unit specification, H is the total harvested mass, and PC is the processing cost. Labour costs, management/training, fuel, and utilities are the last costs listed. Each one is proportionately represented for each species according to the ratio of grow-out volume allocated to that species. So if cobia has twice as much grow-out volume as snapper, for example, the labour costs for that year would be represented as two thirds in the cobia worksheet and one third in the snapper sheet. This assumes the labour, training, fuel, and utilities are used in those same proportions to produce each species so the costs should be reflected as such. Labour costs are taken from the 'Payroll' worksheet for each year, while management/training, fuel, and utility costs are based on estimates from other aquaculture facilities in the tropical regions of the Americas. The management/training line item represents costs associated with consulting, or hiring outside help to train local staff. This has been an appreciable costs to other aquaculture farms.

The bottom rows give the bottom line numbers beginning with summation of costs. Operating costs is the sum of the cost of stocking fish in cages, feeds, processing, packing and shipping, labour, management, fuel, and utilities. Capital investment is linked to that year's total from the 'Capital Costs' worksheet. Total investment is the sum of the two previous rows. Gross profit is the revenue less operating costs, and net profit is the revenue less total investment. The next line is headed "Cumulative profit" and sums the net profit (or loss) of that year with every year before it. It is negative in the early years and becomes positive after the breakeven point. The next row has just one value which is the IRR calculated using Excel's IRR function and the net profit row for the 10 years. The last row calculates the NPV using Excel's NPV function using the net profit from the 10 years as well as a user inputted discounting rate.

Since the model is intended to be an early stage assessment tool, the sensitivity analysis is designed to be interactive and user friendly, while still providing insight into the effect of each variable on bottom line numbers. The worksheet is divided into four boxes (figure 3). The box on the top left lists the manually inputted parameters for the economic analysis of each species. The percent change column of this row allows each parameter to be modified individually or together by set percentages. The adjusted values show that parameter for each species adjusted by the specified percent. Both positive and negative changes can be input here to simulate better than expected or worse than expected scenarios. The formulas are written such that a positive change always creates an improvement in the parameter. For example, grow-out time is given in days and fewer days to reach markets size is preferable to more days. As such a 5% improvement in

Variable	Percent Change	Adjusted Value (Cobia)	Adjusted Value (Red Snapper)
Grow out Time (days)	0%	360	360
Growout Volume (cages)	0	12	12
Survival Rate	0%	85%	85%
Stocking Density	0%	23	20
FCR	0%	1.8	2
Cost of Feed	0%	$1.80	$1.80
Percent Yield	0%	70%	80%
Market Price	0%	$6.50	$5.25

Sensitivity of Main Variable			
Variable	Annual Profit	IRR	NPV
Grow out Time (days)	1.21%	1.09%	1.53%
Growout Volume (cages)	9.27%	3.51%	9.22%
Survival Rate	0.09%	0.13%	0.16%
Stocking Density	1.11%	1.27%	2.22%
FCR	0.74%	0.56%	0.65%
Cost of Feed	0.74%	0.56%	0.65%
Percent Yield	2.10%	1.99%	3.05%
Market Price	2.10%	1.99%	3.05%

Annual Production (at full production)		
Parameter	Cobia	Red Snapper
Volume Produced (kg whole)	1,343,200	1,168,000
Variable Costs / Cage	$543,111	$518,537
Revenue / Cage	$1,122,806	$901,249
Gross Profit / Cage	$579,694	$382,711
Variable Costs	$6,517,337	$6,222,450
Revenue	$13,473,667	$10,814,984
Gross Profit	$6,956,330	$4,592,534
Total Variable Costs	$12,739,787	
Total Revenue	$24,288,651	
Gross Profit w/o Labour	$12,729,904	
Gross Profit	$11,548,864	

Ten year Total			
Total Invested in Capital	$18,593,731		
Total Invested	$97,461,861		
Total Revenue	$143,925,655		
Total Profit	$46,463,794		
IRR	39.82%		
Net Present Value	Rate:	10%	$19,613,183

Figure 3: A screenshot of the four elements included in the sensitivity analysis.

grow-out time will decrease the number of days by 5% (the value is multiplied by 1 minus 0.05). For survival rate a higher number is preferred so the value is multiplied by 1 plus 0.05 to improve the value by 5%. The grow-out volume row receives change in number of cages, not percent increase or decrease, as this is a discrete variable while the others are continuous. The two boxes on the right, titled "Annual Production" and "Ten year Total" give a summary of key statistics but accounting for the altered values in the first box. This allows the user to explore various scenarios and receive an instant feedback with each of these stats. The values in the "Annual Production" box are based on full scale production (year 10) values. The last box, titled "Sensitivity of Main Variables" calculates the percent change in annual profit, IRR and NPV for each 1% change in each variable. For grow-out volume the value is the percent change in profit, IRR and NPV per cage increase or decrease for both species. These are calculated using a set of hidden cells which produce a new 10 year loss/profit row for each parameter with that parameter multiplied by 1.01 or 0.99 each time it appears (depending if improvement is an increase or decrease for that parameter). This adjusted profit, IRR or NPV is divided by the unadjusted value and then has 1 subtracted from it.

There are two production plans, one for each species (the cobia production plan is shown in figure 4), which roughly outline the schedule of costs and production. These only summarize what is already presented elsewhere in the workbook, but give a holistic view of the production volume in a comprehensive page. Many farm managers use production volume as a metric to compare farms and predict success.

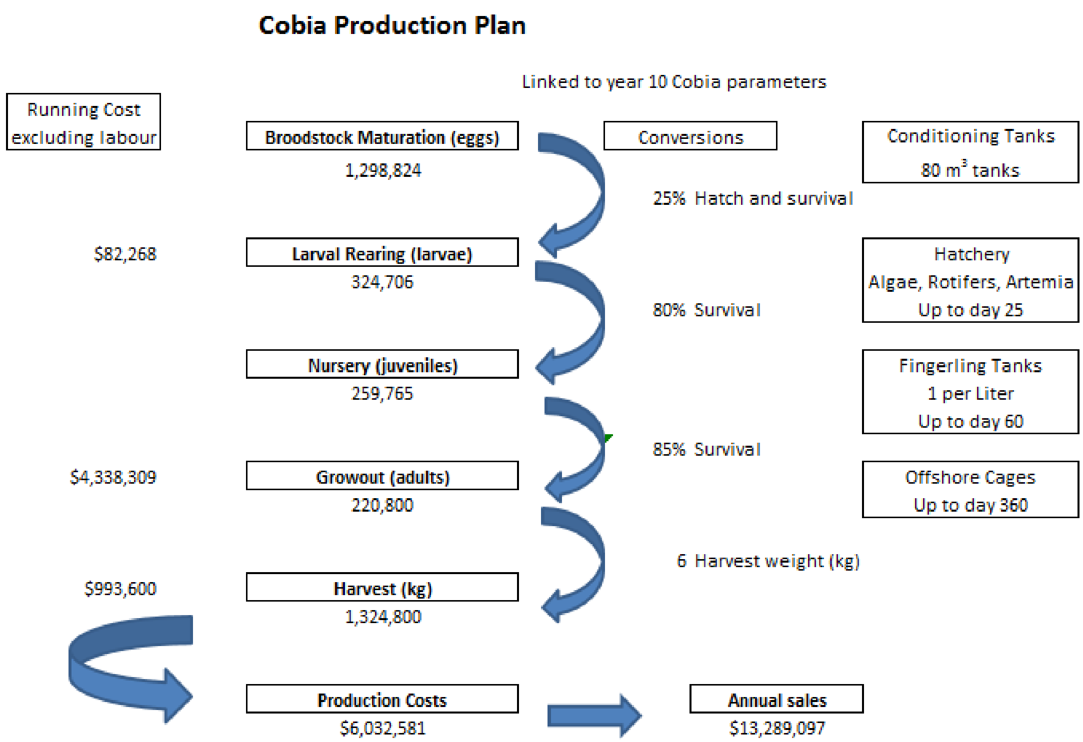

Figure 4: Production plan for cobia at full operating capacity. Taken from the 'Production Plan – Cobia' worksheet.

<u>Limitations of the Model:</u>

The state of the industry in this region of the world provides few examples upon which to gauge the strength of the model. With only a few points of empirical evidence as support, the model must be accepted on the merit of its theoretical accuracy. Although this is a weakness, the lack of real examples of success or failure is why the model, and aquaculture models in general, is necessary. A mature industry will still apply predictive models to their business plans but with reduced emphasis as they will have access to real values from multiple farms upon which to base their profit, IRR and NPV projections (Knapp 2013). Until the industry matures, predictive models are the best tool available. UMEH has been successful using models very similar to the current one to project the cash flow and growth of start-up offshore aquaculture companies in Central and South America.

Although other farms comparable to the theoretical farm modeled here have achieved the same growth and market metrics, they consistently take longer to produce at full capacity and become profitable. There are three main assumptions as well as an innate error in the model which cause this discrepancy. These are the assumption of unlimited seed stock, the unpredictability of setbacks, accidents or disasters, and the assumption of a stable and insatiable market place. The model predicts earnings before taxes, and insurance (EBIT). These factors can represent a significant costs but vary by region and situation.

The model is built such that all the grow-out volume available will be filled to the desired capacity. A hatchery should be built with sufficient capacity to supply these needs and an alternative reliable source of fingerlings should be found before a project gets underway. It takes a while before a hatchery can produce fingerlings consistently and this is accounted for in the modeled example by putting the cost of fingerlings at $3.50 (the cost to buy fingerlings from an outside source) for the first two years. Despite this, fingerling production is always uncertain regardless of whether fingerlings are sourced internally or from another hatchery. Underutilized grow-out space is a major cost to a company which is under appreciated in the model.

Delays in construction, permitting, hiring ideal employees, etc. does not affect the parameters in the model but delays the progression of the business development which reduces the realized profits, IRR, and NPV as the profits are received further in the future. Delays such as this are difficult to anticipate yet inevitable. Natural disasters, such as severe weather which occurs regularly at most grow-out sites, can delay production, resulting in missed feedings or damage to equipment. These all lead to reduced investment performance and are difficult to anticipate and model.

The last assumption is that the market price will be stable and that all of the product will be sold at that price. Prices for marine sea food products typically vary seasonally as well as yearly. Aquaculture has the advantage over wild fisheries of controlling, to some extent, the timing of their harvest as well as the species grown. Additionally, the reliability of their product allows them to negotiate larger volume contracts for future purchases. This mitigates the some of the effects of a dynamic market place, but does not eliminate the divergence of actual sales from the model predictions.

Interpretation of the Example:

The values plugged into the model represent a hypothetical investment opportunity to build a marine finfish hatchery and grow-out site in Central America. The assumption is that no infrastructure is in place and that cobia and red snapper are the selected species. The location and species were selected due to the presence of several aquaculture farms growing these species in this region and the availability of their growth metrics and certain expenses. The values presented have been modified from those observed at those farms both to protect the companies and to more accurately reflect what the values would be for a new company building upon updated knowledge and technology. For example, there has been lot of research going into cobia nutrition in the past few years (Suarez *et al.* 2013; Fraser and Davies 2009**)** and these advances should be reflected in commercially available products soon. This will allow new farms to show improved growth metrics and reduced feed costs which existing cobia farms did not have in their early years of operation.

The summary of key stats is the first page presented in the model. The parameter assumptions (table 1) are in line with what is observed in the industry and literature (Sardenberg 2011; Liao *et al.* 2004). Variable costs are \$444,047 and \$545,295 per cage per year for cobia and red snapper respectively while revenue is \$972,608 and \$979,645 per cage per year bringing gross profit to \$528,561 and \$434,350 per cage per year. Based on these values the farm could increase their profit by \$94,211 each year for each cage they switch from growing red snapper to cobia although this does not account for the benefits of multiple products as mentioned above. Total annual variable costs are \$5,328,561 and \$6,543,535 for cobia and red snapper respectively and annual revenue is \$11,671,294 and \$11,755,739 bringing gross profit to \$5,874,925 and \$5,212,204 for cobia and red

Table 1: Assumptions of key parameters used in the model

Summary of Key Numbers (annually for full stocking of each species)		
Parameter	Cobia	Red Snapper
Cost per Fingerling	\$0.318	\$0.354
Cost per Kg Feed	\$1.80	\$1.80
FCR	1.8	2.0
Stocking Density	20	23
Total Production (kg whole)	1,152,000	1,269,600
Market Price \$/lb	\$6.50	\$5.25

snapper. Farm wide annual revenue, at $23,427,003, minus variable costs at $11,872,096, gives a profit at full scale production of $11,554,937 per year.

The total capital needed for the first year of operation is $3,271,734 but a total of $8,738,535 is needed before the company becomes profitable. Year 5 is the first year of profitability. Through the first 10 year of operation, the company will invest $18,045,331 in capital. The total cumulative profit after 10 years is $43,540,405 with an IRR of 36% and NPV of $17,426,981. This is a high risk – high reward investment. The IRR and NPV are competitive against other investments on this scale, but there is a long payout period and high uncertainty.

The values in the ‘Capital Costs’, ‘Payroll’, and ‘Hatchery Costs’ worksheets can vary regionally and by source, quality, and other factors. The inputted values have been confirmed by hatchery managers at UMEH and other aquaculture farms in the Americas to be similar to the values seen at their hatchery. The annual expenses in labour and hatchery costs at full scale production are $1,181,040 and $782,107 respectively (labour at the hatchery is included in hatchery costs, not payroll).

The grow-out economic worksheets takes inputted values and give immediate feedback when these are altered. The most valuable information is the relative size of the expenses. In year 10, feed for cobia is expected to costs $3,732,480 while labour will costs $603,084. This means reducing feed costs by 1% (through better feed management, attention to detail, experience) would offset a 6% increase in labour. In other words, a company should be willing to spend $35,000 in addition to the current expenditures to reduce feed usage by 1%. The total costs, revenue, and profit are separated by species in these sheets which facilitates comparisons. Cobia’s IRR of 40% is higher than red snapper's of 32% and adds over $3,000,000 more to the NPV. Both the breakdown of variable costs as well as the costs, revenue and profit over time are summed for both species summarized in figures 5 and 6 respectively.

The design of the sensitivity analysis allows it to be an interactive tool. The user can make percent changes in whichever assumptions they have less confidence in to model different scenarios very quickly. For example, if an additional cage is added to the

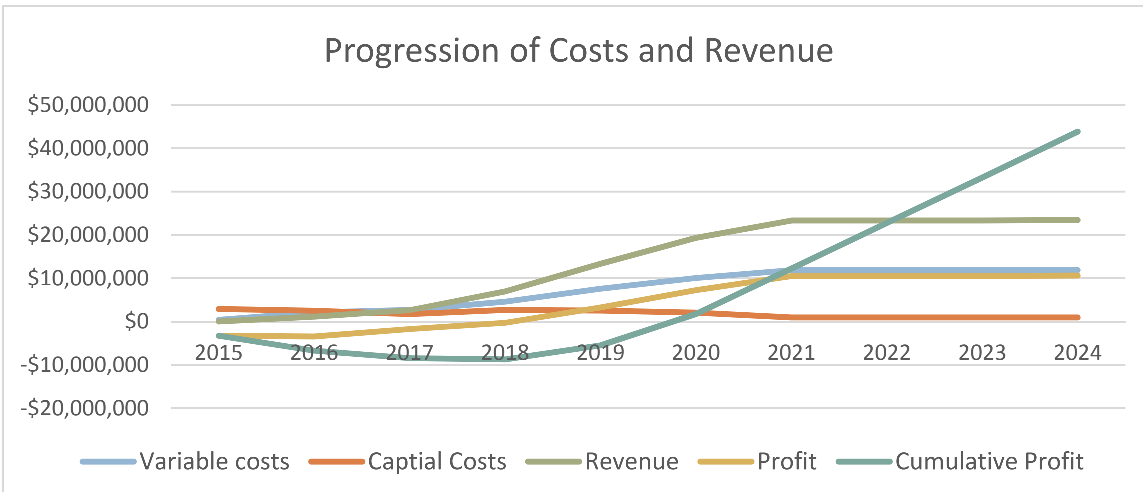

Figure 5: Yearly projections of cost, revenue and profit over the first 10 years of operation

grids for both cobia and red snapper (cages are still added slowly but the total number of cages in increased) then the total 10 year profit raises from $45.4 million to $49.7 million (9.5% increase). IRR raises from 38.67% to 40.17% (3.8% increase) and NPV raises from $19.0 million to $20.9 million (10% increase). If there are concerns with the growth metrics this can be modeled by increasing grow-out time by 10%, reducing stocking density by 5% and survival rate by 5% (these percent changes were chosen arbitrarily for demonstration purposes. Any parameter can be changed by any amount). These changes cumulatively would reduce total 10 year profit from $45.4 million to $34.3 million (24.4% decrease), IRR would drop from 38.67% to 31.54% (18.4% decrease) and NPV would drop from $19.0 million to $13.4 million (29.5% decrease). The sensitivity analysis also has a built in tool to show the percent increase in each of total profit, IRR, and NPV for each increase in each major parameter. These update automatically when

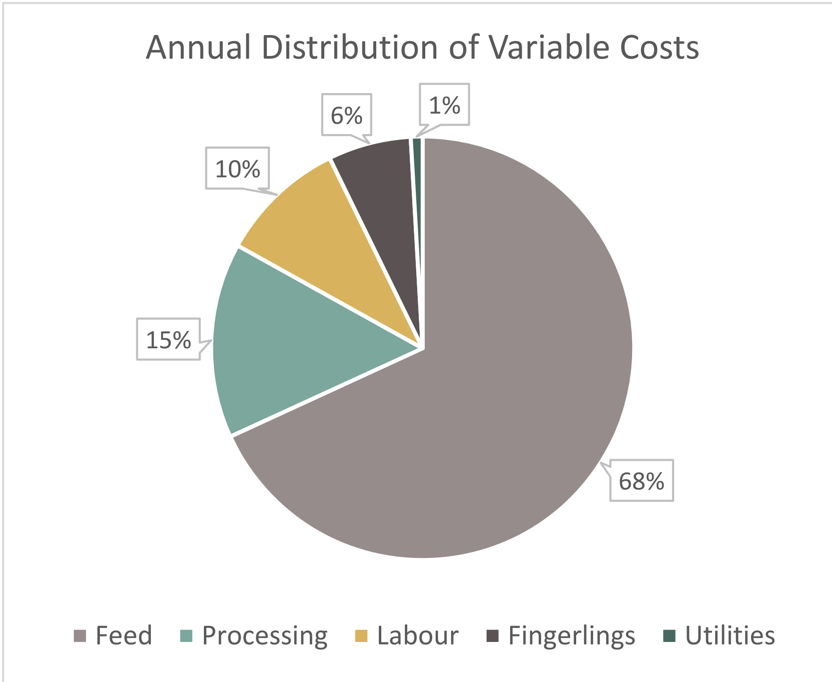

Figure 6: Break down of variable costs at full scale production

changes are made other places in the model. The sensitivity of profit, IRR and NPV to each parameter is shown in table 2. The parameters do not each affect profit, IRR, and NPV in the same way. Changes to grow out time has no effect on capital costs or variable costs and changes only the number of cycles per year, thereby changing only revenue. Stocking density determines

Table 2: The sensitivity of profit, IRR, and NPV to 1% or 1 unit change in each parameter

Sensitivity of Main Variable			
Variable	Annual Profit	IRR	NPV
Grow-out Time (days)	1.21%	1.54%	2.87%
Grow-out Volume (cages)	9.28%	4.12%	10.89%
Survival Rate	0.08%	0.14%	0.17%
Stocking Density	1.11%	1.00%	1.73%
FCR	0.75%	1.01%	1.99%
Cost of Feed	0.75%	1.01%	1.99%
Percent Yield	2.11%	2.46%	4.45%
Market Price	2.11%	2.46%	4.45%

both the number of fish at harvest (effecting revenue) as well as the feed and fingerlings required (effecting variable cost) which makes the relationship slightly different. A rate of change for each variable will further alter their sensitivity. Stocking density, for example, requires no experimentation before the optimal value is determined as a new farm can look to other facilities growing the same species and set copy their stocking densities. FCR, on the other hand, requires experienced managers, well trained staff, reliable technology (cameras, oxygen probes) and a well formulated feed to optimize. It can take several years for a farm to reach their stabilized economic FCR. Given that IRR and NPV depend on the timing of costs and revenue as well as the magnitude, each variable may have a more dramatic effect on one than the others. Grow-out volume is unique in that it is the only parameter that is not continuous. A manager cannot increase the grow-out volume by 1%, but only in increments of a cage. As such, the numbers represent the effect on profit, IRR, and NPV for 1 cage being added to the grow-out volume of both species. This is an 8.3% increase per cage if the grow-out originally has 12 cages per species. The effect of a 1% increase in grow-out volume would be 1.12% on annual profit, 0.50% on IRR and 1.31% on NPV. This makes it slightly less important than stocking density which is not surprising as both lead to direct changes in number of fish grown. Cage volume has capital cost associated with it which is why these parameters are not identical. Survival has the smallest effect on all the economic indicators but this is due partly due to the structure of the model. Mortalities in real life represent two significant costs; loss of saleable fish (or underutilized grow-out space) and expended cost to grow that fish to that size (fingerling production, feed, etc). The model assumes that survival rate is anticipated and each cage is slightly over stocked to account for losses and reach a target stocking density by the time the fish reach harvest size. This eliminates the missed revenue from underutilized cages from the model as this should also be done by operating farms. The value of the feed consumed by the fish before they die is also not included. This is due to the difficulties in modeling such a factor and the relatively small effect of this cost on the bottom line. This cost is significant, however, when examining the importance of survival individually. As such, the survival rate affects only the number of fish stocked in the cage and the cost of those fingerlings. The cost per kg feed and FCR both directly affect the total cost of feed. As such they are identical to each other. Likewise, market price and percent yield both directly affect the revenue generate by the harvest either through the total amount of product (as in percent yield) or value per unit product (as in market price) but in either case will affect revenue in the same way. Changes in percent yield and market price have the most dramatic effect on profit, IRR and NPV.

Chapter III

Remote Site Assessment

<u>Purpose and Alternatives:</u>

The application of remote site selection protocols will fill two primary functions. The first of these is to identify areas with a high potential for industry growth. This is of interest to policy makers, aquaculture support industries (feed mills and cage manufacturers for example), and aquaculture investors who have yet to engage in any level of consulting. The second function is to aid in the selection of specific sites within an area of interest for investors who have a plan and are ready to begin with farm design. Since the operation and ideal conditions for an aquaculture facility are so varied based on the culture method and species selected it is important to have a site selection model which is specific to the goals of the investor. The proposed site selection protocols will model the site selection process for offshore grow-out of tropical marine finfish. The inputted values will be those ideal for growth of cobia. The protocols outline can be modified for any marine species grown in cages but the site selection criteria for land-based or coastal systems would be too dissimilar to consider the proposed model sufficient.

Models using Geographic Information Systems (GIS) to select aquaculture sites already exist and are becoming increasingly utilized in the industry. A model has yet to satisfy the functions listed above as existing models are either unavailable to users, too broad in scope (Kapetsky and Aguilar-Manjarrez 2013; Kapetsky *et al.* 2013; Meaden and Aguilar-Manjarrez 2013; Ross *et al*. 2013; Nath *et al.* 2000), pertain to another region or species group (Asmah 2013; Cross 2013; Karakassis 2013; Lundebye 2013; Sadek 2013; Silva *et al*. 2011; Longdill *et al.* 2008; Reyahi Khoram *et al*. 2005), or are not designed to find ideal sites for operation (focus solely on environmental, economic or political issues; Byron and Costa-Pierce 2013; Sutherland *et al.* 2009; Corner *et al.* 2006; Cromey *et al.* 2002). A study by Falconer *et al.* (2013), for example, examines the environmental constraints of cage design and deployment but does not address the biological needs of the fish.

FAO's GISFish is a portal with links and citations to many publications, activities, training, data, and tools which address spatial applications to aquaculture and fisheries (Aguilar-Manjarrez *et al*. 2010). Although a very useful resource, GISFish does not identify sites on its own although it does include links to projects and publications that do (Gifford *et al*. 2004; Arnold *et al.* 2000; Kapetsky and Nash 1997). AIMS' Cage Aquaculture Decision Support Tool (CADS_TOOL; available via www.aims.gov.au/en_GB/docs/research/sustainable-use/tropical-aquaculture/cads-tool.html) is designed to classify and compare several identified sites which have already been assessed and had parameters taken. It does not find and evaluate sites remotely.

Modeling the particulate waste of marine cage farms has received much attention and these models are quite accurate (Corner *et al.* 2006; Cromey *et al.* 2002). Some depositional models (frequently referred to as DEPOMOD) can predict particle accumulation to within 13% of observed values (Keeley *et al.* 2013; Cromey *et al.* 2002) in certain situations although other models of a similar nature have shown accuracies between 50 – 70% (Corner *et al*. 2013). In either case, these models can be quite valuable in assessing environmental impacts of cages or maximum stocking densities but do not address the first need faced by aquaculturists; identifying optimal sites within a region to place cages. Depositional models may be quite useful as part of the permitting process but are insufficient for feasibility assessment and farm planning.

Aquamodel is a plug-in developed for *EASy* GIS software which is designed to aid in aquaculture farm management. This product has been successful in selecting grow-out sites for fish farms (Rensel *et al*. 2013) but is currently unavailable to most users as it is only being licensed to governments and a limited number of professionals. This program is very thorough but requires many inputs, time, and man power to run. A study done in the United Arab Emirates (Rensel *et al.* 2013) required external funding and three investigators. Other site assessment studies using Aquamodel (Kiefer *et al.* 2011; O'Brien *et al.* 2011) required similarly labour intensive inputs. The Aquamodel software incorporates 3-dimentional flow and micro-hydrodynamic models which are very difficult to build as that data is unavailable for most parts of the world and must be measured in the field. Aquamodel also uses physiological parameters from the selected species to generate particulate waste predictions which combined with hydrodynamic models can produce waste accumulation predictions. Aquamodel also uses many other parameters such as bathymetry, temperature, and plankton density but these are more readily available. This level of detail is unnecessary for the site selection process and the time and resources required to produce such models would dissuade investors from proceeding with the study. The current model can be run in a day or two from any computer with internet connectivity and the more popular ESRI ArcGIS software. The accessibility and ease of running a model is important as the model serves as an initial indication of feasibility and makes recommendations for sites which must then be visited.

Site visits are an essential component of site selection and are unavoidable regardless of the model used to select the site. Site visits include non-measurable data such as availability of skilled laborers, political climate and favorability towards aquaculture development, and quality of infrastructure. At this later stage of farm planning, a deposition model or Aquamodel program may be beneficial if it facilitates the permitting process.

The proposed model will be built with ESRI's ArcGIS software. It will use remotely sensed data but is able to accommodate manually entered data (for example locations of processing plant, or pre-existing offices and infrastructure). The model can also be updated with data from ground truthing studies to confirm and further specify grow-out site locations but this is not the primary function of the model.

A holistic site selection process must identify and grade the criteria appropriate for the species selected, the ideal grow-out system for that area, as well as the socioeconomic criteria needed for a business to succeed (Benetti *et al.* 2010a; Beveridge 2004). Oceanographic and atmospheric data is often available at good resolutions for any area of interest, particularly for parameters which can be measured using remote sensing technologies. This is not the case, however, for political, economic, and demographic data. Local acceptance of a project and availability of skilled manpower are two factors identified by Benetti *et al*. (2010a) as important factors in site selection but these are difficult to include in GIS systems and the availability of data is largely non-existent until a site visit is made. As such they are not included in the model. Legal frame work and an effective permitting process are also essential elements of site selection. These factors vary dramatically between countries and regions and are not included in the protocols described here. The application of the model, when working with a client and a specific area in mind, could include these factors if a spatial component exists in the legislature. The legal and socioeconomic factors are important to consider in determining the feasibility of a region for an aquaculture farm, but are less relevant for pin pointing a specific site within a region of interest. Therefore, omitting these from the protocols will not reduce the value of the model as it is assumed that these criteria will be discussed independently of the spatial analysis. In many cases, legal and socioeconomic factors will remove or discourage certain regions from consideration before a site selection study begins based on the client's or consultant's previous experience with the region. Detailed analysis of these factors is much more resource intensive (cost and man power) so best left until promising sites are identified with oceanographic criteria.

The model will select sites optimal for growing cobia in submersible cages. Submersible cages are necessary for most sites in the region due to hurricane risk. Cobia is a very attractive candidate for aquaculture in this region and has already been selected by active industry members (Open Blue and Marine Farms Belize). Cobia was selected over other prospective and commercially cultured species due to its frequent appearance as the representative species of tropical marine offshore aquaculture (Lovatelli *et al.* 2013; Ross *et al.* 2013; O'Brien *et al.* 2011; Posadas and Bridger 2004)

Establishing the Protocol:

Data was collected from online sources as summarized in table 3. The data covered the Gulf of Mexico, The Bahamas and the Caribbean Sea covering an extant of 59°W to 101°W and 8.5°N to 30°N. Areas in the Pacific Ocean were excluded.

Table 3: Data sources for analysis remote site selection protocols.

Parameter	Source Organization	Website / Satellite	Spatial resolution	Temporal resolution
Bathymetry	NOAA	gulfatlas.noaa.gov	2.1 km cells	NA
Temperature	NOAA	AVHRR Pathfinder	5.3 km cells	Daily
Salinity	NOAA NODC	www.nodc.noaa.gov	¼ degree cells	Annual
Current	NOAA	www.oscar.noaa.gov	⅓ degree cells	5-Day
Chlorophyll	NASA	oceancolor.gsfc.nasa.gov/	5.3 km cells	8-day
Hurricanes	NOAA NHC	www.nhc.noaa.gov/	NA	1851-2012

The general flow of the analysis is shown in figure 7. Bathymetry, temperature, current, and chlorophyll came as raster data. Temperature, current, and chlorophyll was taken daily or as multiday composite rasters and the average, maximum and minimum values were calculated using the cell statistics tool. Minimum chlorophyll was not calculated as the minimum values have no bearing on site selection. All three datasets included data from 2011 to 2013. The salinity data came as a point file with a point every quarter of a degree (11350 points in the area of interest). This layer was interpolated into a raster layer with a resolution of 2km using the inverse distance weighted (IDW) method using a power of 3 to diminish weights of further points and a search radius of 4 points. This created a raster which was analogous to the point layer. Given the high density of points and the regular spacing of them, the IDW method is the most appropriate interpolation method as error is expected to be very low. Different methods such a kriging could smooth the extremes of the data which is important to maintain.

The hurricane data also came as a point layer. Points appeared where measurements on wind speed and pressure were taken. The data source does not state how these locations are determined. Hurricane tracks were created using the point to line

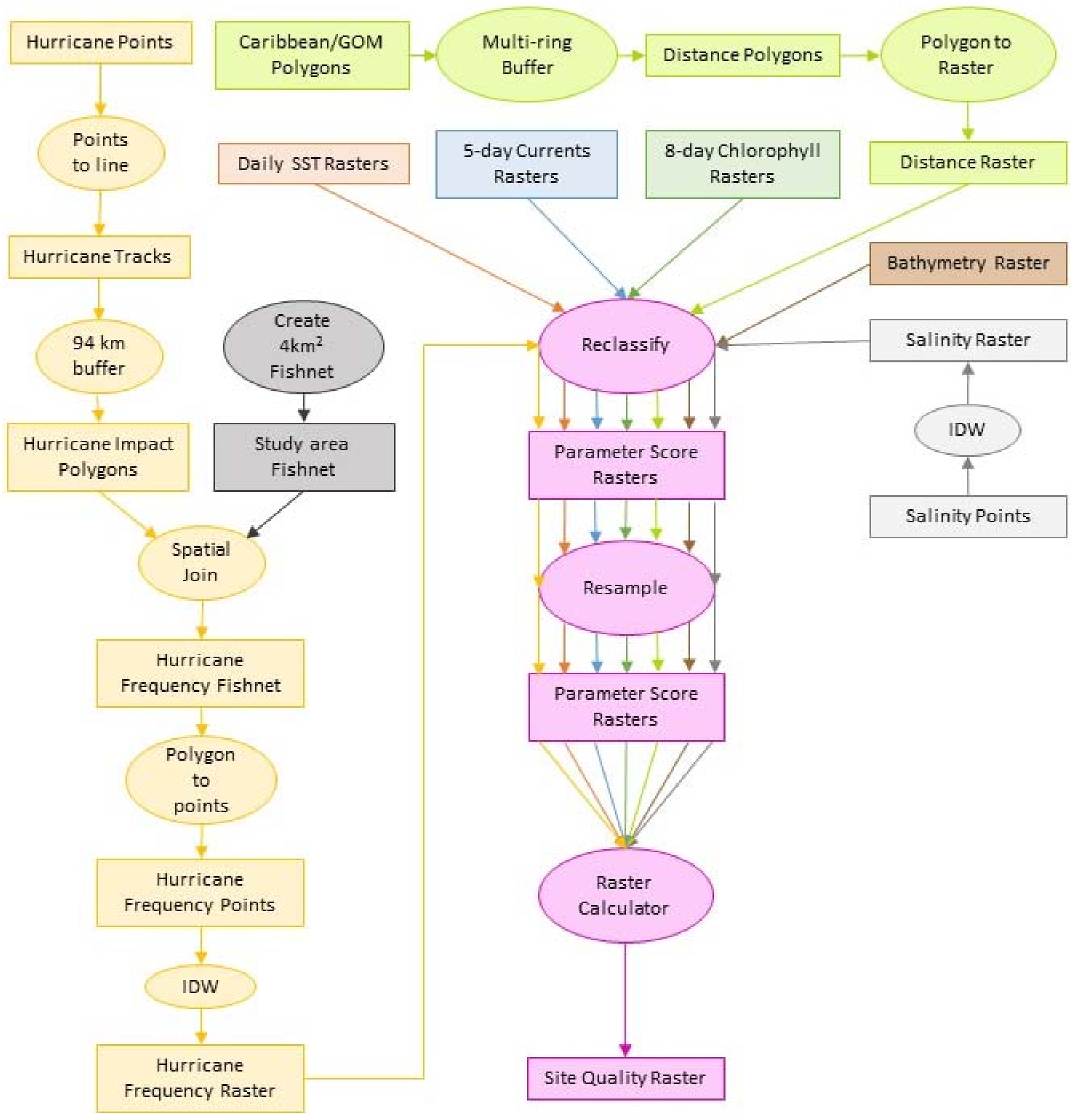

Figure 7: Flow of operations for site selection protocols

tool such that each unique hurricane number for each year had its own track (unnamed hurricanes or hurricanes with the same name remained unique). The hurricane tracks were summarized by year to observe trends in hurricane frequency (figure 8). A change-point analysis revealed mean changes in year 1966 (100% confidence, change-point analyzer from Taylor Enterprises Inc.) as well as year 1995 (98% confidence, change-point analyzer from Taylor Enterprises Inc.). Whether these changes are a result of changes in sampling techniques or real changes in hurricane frequency is not relevant to

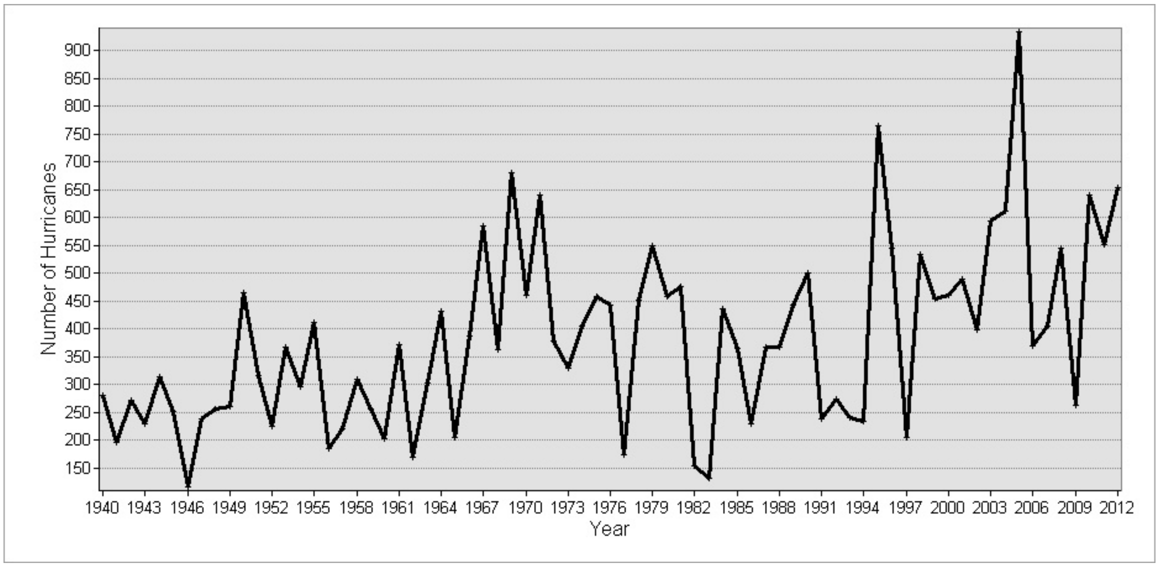

Figure 8: The number of hurricanes in the Atlantic Ocean by year since 1940

the model as long as the data set provide a good estimate of hurricane frequency in the near future. Hurricanes occurring before 1966 were removed from the layer. Hurricane tracks occurring from 1966 onward were buffered to create an area of impact for each hurricane track. There is not enough data on hurricane damage to aquaculture cages to determine a critical wind speed, pressure, or category which will cause damage. As such, a value of twice the radius of maximum wind speed was used for the buffering distance. Radius of maximum wind speed cannot be consistently modeled as a function of wind speed or storm center pressure (Mrowiec *et al.* 2006; Willoughby 2006), so an average value of 47km (Hsu and Yan 1998) was used for all tracks giving a buffer radius of 94km. A fishnet with cells of 4 km^2 was created over the same extent as the hurricane tracks and then joined spatially to the hurricane track buffer areas. This creates a count field with the total number of hurricane events affecting each cell. This field was divided by the number of years to give the number of hurricanes which affect each cell per year. The fishnet was converted to a point layer and the points were interpolated using the same method as the salinity raster to create a raster of hurricane frequency (figure 9). All layers were projected into North America datum Equidistant Conical projection system.

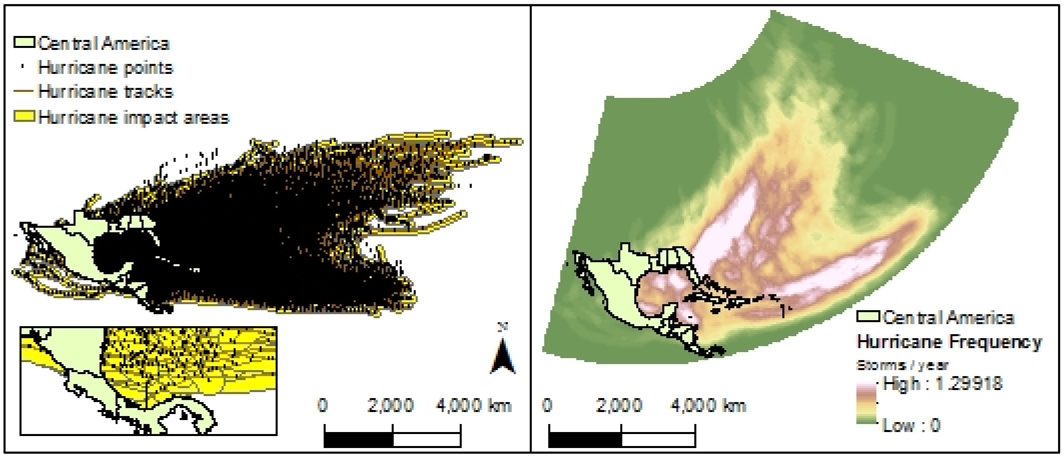

Figure 9: Left: Hurricane points, tracks and buffer zones. Right: Projected hurricane frequency raster

Each raster was reclassified according to an approximation of its relative effect on company profit. For the temperature raster, for example, temperatures too cold for growth would be given a score of 0. The minimum temperature range for commercially feasible growth would be scored at 1 and the score would increase as temperature values approach an optimal values. There is not complete data to determine this for any species so approximations were created using sources for different species, locations, and rearing methods.

Temperature has a dramatic effect on growth rate (Fang *et al.* 2010; Schwarz *et al.* 2007; Sun *et al.* 2006; Imsland *et al.* 2001) but growth also has interactions with salinity (Imsland *et al.* 2001) and other parameters (Fang *et al.* 2010; Sun and Chen 2009) which makes it difficult to evaluate independently. It is difficult to compare data points from different data sources as each study will use different stocking densities, diets, and other factors which affect growth and performance. Best estimations were made using all available data.

Schwarz *et al.* (2007) examined the growth rates of cobia at 18, 23, and 29 °C. Over a 70 day period, cobia held at 18 °C showed only a 10% increase in body mass, whereas fish held at 23 and 29 °C showed 108% and 197% increases. Standard growth rates were 0.13, 1.05, and 1.52 for the three temperatures respectively. Although there is no critical growth rate which is deemed commercially viable, cobia should reach a harvestable size (4-6 kg) in close to 360 days (Benetti *et al*. 2010b). Cobia grown in the Bahamas at 25.5 °C reached 3kg with a specific growth rate of 2.04 (specific growth rate is calculated as SGR=100* (ln W_2−ln W_1)/(t_2−t_1) in both articles but inconsistencies in reported SGR occurs from different feeds and stocking densities used in each). As such, temperatures below 25°C were classified as insufficient for commercially feasible growth, and given a rank of zero for the reclassified average temperature raster. A grow-out trial in Brazil produced 4kg cobia (the minimum harvest size) in 360 days at an average temperature of 25°C (Sampaio *et al*. 2011) which confirms that 25°C is the minimum viable temperature for commercial grow-out of cobia. Cobia grown in Puerto Rico at an average temperature of 27.8 °C reached 6kg in 360 days (Benetti *et al*. 2010b) indicating that an average temperature of 28 is close to ideal. Considering the increase in growth rate between fish held at 23°C and 29°C in the Schwarz *et al.* (2007) study (82% improvement) and the fish grown at 25.5 and 27.8 °C in the Benetti *et al.* (2010b) study (50% improvement), site with a temperature between 25 and 26°C were given a rank of 1, temperatures between 26 and 27°C a rank of 1.25, 27 and 28°C a rank of 1.5 and 28 and 29°C a rank of 1.75. In a study by Sun and Chen (2009) fish grown at 33°C showed a 22% increase in SGR over fish grown at 27°C when fed to satiation but Sun *et al*. (2006) observed SGR decreasing by 3% between fish raised at 27°C and 31°C. Sun and Chen

(2014) observed an increase in SGR from 27°C to 31°C of 22.8% and a further increase of 5.7% when increase from 31 to 33°C. As such, sites with a temperature between 29 and 33 °C will be given a rank of 2. Sun *et al.* (2006) observed a decrease in SGR of 238% between fish grown at 31 and 35°C. This decrease in growth rate at 35°C was also observed by Sun and Chen (2014). Above 33°C fish may start to suffer from heat stress as the upper lethal limit for cobia is 37.7°C (Shaffer and Nakamura, 1989). Temperature between 33 and 35°C were given a ranking of 1.5 and above 35°C a ranking of 0. Temperature can also effect FCR but this is less supported within the ranges of normal growth (Schwarz *et al*. 2007) and FCR is affected by other factors much more dramatically than temperature (feed most importantly; Chou *et al.* 2004; Romarheim *et al*. 2008) which makes discerning relationships difficult. Sun and Chen (2014) found no difference in FCR between fish grown at 27, 31 or 33°C and only outside this range did FCR drop significantly. Temperature is considered to affect only growth in the current study as this is the most consistent and quantifiable relationship but temperature can also affect disease occurrence, fouling rate, and other cost incurring factors. The average sea surface temperature raster and reclassified raster are shown in figure 10. Subsequent oceanographic parameter rasters and reclassified rasters are not shown.

Schwarz *et al.* (2007) found that cobia who were stunted from being held at 18°C showed compensatory growth but Liao *et al*. (2004) report permanent stunting and mortality at 16°C The minimum temperature raster was reclassified such that temperatures below 16°C were given a score of 0 and everything else a value of 1. The maximum temperature raster was reclassified such that values above 35°C were given a value of 0 and everything else a value of 1.

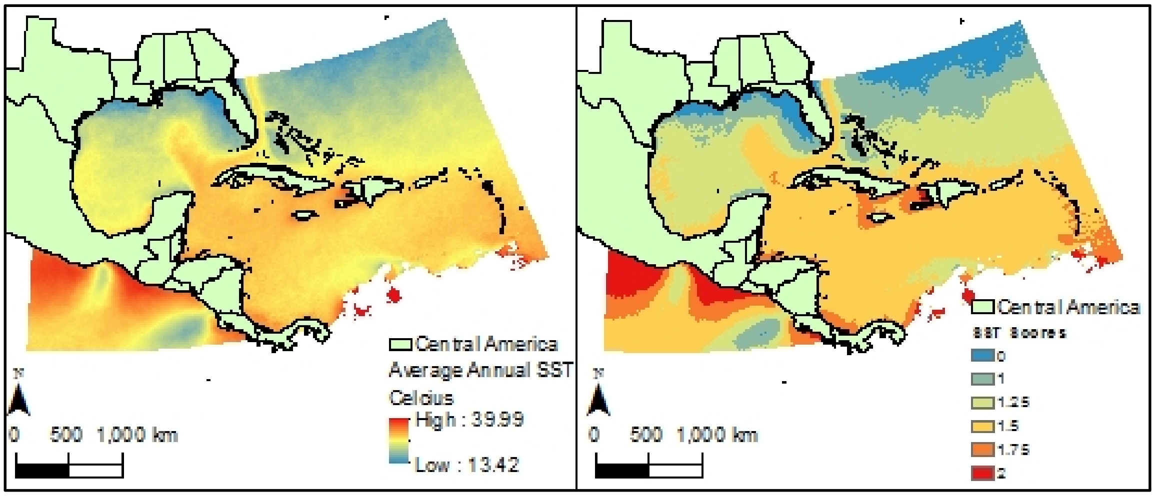

Figure 10: Left: Average annual SST for the area of study. Right: The average annual SST raster reclassified into graded scores.

Salinity also effects growth and FCR by creating osmotic pressure on the fish. Boeuf and Payan (2001) review this topic and suggest that salinities closer to isosmotic will result in better growth and feed conversion. This has been observed in marine species (Imsland *et al*. 2001) but actual reported effects vary between accounts (Chen *et al*. 2009). Stieglitz *et al*. (2012) found that cobia can survive higher stocking densities during shipping at 12 ppt versus 32 ppt indicating that cobia do experience some level of stress relief at lower salinities. There is only small variations in feed conversion and standard growth rate with cobia showing no significant difference at salinities of 15, 20, 25, and 35 ppt but improved FCR and SGR at 30 ppt by 13 and 11% respectively (Chen *et al*. 2009). As such, the salinity raster will be reclassified such that values between 28 and 33 will have a value of 1.1, values between 15 and 28 and above 33 will have a value of 1, and all other values will be 0.

Ocean currents affects both the living environment of the fish, as well as the working environment of the farm workers and physical environment of the cages. In some cases, current velocity can become so extreme that it affects the cage infrastructure and create costs in damaged or lost equipment which can lead to escapes. Cobia swim at approximately the same rate regardless of the current within a range of 0 – 100 cm/sec and can rest on the bottom of the cage in currents as high as 50 cm/sec (Drew Davis, personal communication; personal experience, Cape Eleuthera Institute). The energetic cost of swimming in different currents within this range is not believed to be significant. Moderate currents are essential, however, to flush out old water from the cage which has ammonia, feed debris, and possibly the mobile life stages of parasites and also to bring in new water rich in oxygen (Beveridge 2004). It is difficult to quantify the benefit of additional water flow, and the cost of less efficient labour must also be considered. SCUBA divers cleaning the cages, or collecting mortalities will work less efficiently at currents above 50 cm/sec. Ideal currents are between 10 to 75 cm per second (Benetti *et al*. 2010a). This range has been used in other aquaculture siting models (Nath *et al*. 2000 and similar to Falconer *et al.* 2013), although lower velocities have been used for more in-shore production systems (Keifer *et al*. 2011). As such, average currents between 10 to 75 cm/sec are sufficient and those between 30 and 50 cm/sec are ideal. These values will be reclassified as 1 and 1.2 respectively to signify a moderate improvement in site attractiveness considering both a healthy environment for fish as well as ease of work for divers.

Chlorophyll α has been used in other site selection studies as a proxy for natural productivity or dissolved nitrogen (Kiefer *et al.* 2011; O'Brien *et al.* 2011; Gifford *et al.* 2004). This can be used to predict both algal bloom events as well as fouling rates (Rensel and Forster 2005; Marra *et al.* 1990). Fouling rate is more difficult to predict as some sites foul primarily with photosynthetic organism which rely heavily on nitrogen and sunlight whereas other sites foul primarily with heterotrophic organisms which rely primarily on suspended organic debris (Rensel and Forster 2007). In either case, fouling rate are generally considered to be slower in oligotrophic waters which are characterize by low chlorophyll α levels (O'Brien *et al.* 2011; Marra *et al.* 1990). Chlorophyll α levels below 0.3 μg/L (mg/m^3 is an equivalent unit) are considered to be oligotrophic (O'Brien *et al*. 2011) but values as high as 7 μg/L (Gifford *et al.* 2004) have also been considered to be suitable for aquaculture in high energy environments. The costs incurred from high chlorophyll α levels include the labour costs of cleaning cages with higher fouling rates as well as potentially decreased fish growth in a less pristine environment. High phytoplankton levels can reduce dissolved oxygen which impacts fish health. Neither of these effects have been definitively correlated with specific chlorophyll α levels, and the relationship would not be linear as many factors influence fish health and fouling rates. Chlorophyll α values below 0.3 μg/L were given a value of 1.3, values between 0.3 and 1 μg/L were given a value of 1.2, values between 1 and 3 μg/L were given a value of 1.1, and values between 3 and 7 μg/L a value of 1. All other values were reclassified as 0.

Frequency of hurricanes is a difficult parameter to classify as the cost associated with it can be very high but the risk changes dramatically with the cage type. Hurricanes can cause damage to cages and offshore infrastructure which is costly itself to repair but can also lead to escapes. In Norway, from 2001 to 2009, escapes for three species averaged 0.19% of stocked biomass for Atlantic salmon, 0.40% for trout, and 1.02% for cod (Jensen *et al*. 2010). The highest escapes in a year for each species was 0.38%, 0.92%, and 1.89% for each species respectively (Jensen *et al*. 2010). These numbers are likely underestimates due to lack of detection and reporting, but this represents a huge cost to the industry even if insurance claims may offset some of the losses (Jenson *et al.* 2010; Naylor *et al.* 2005). The cause of these escapes varied by species with structural problems causing 68% of escapes in salmon, 36% structural problems and 56% biological problems (predation by seals) in trout, and 38% external problems (exploration, biting holes) and 25% biological problems (predation) in cod (Jenson *et al.* 2010). Siting cages in less storm prone areas would reduce structural damage and associated losses. This could represent and significant savings. Losses in hurricane prone areas such as the Caribbean Sea, Gulf of Mexico and The Bahamas can be even more severe. Reports of cages being removed from the sites have put farms out of business such as a pompano farm in Spanish Wells, Bahamas (Daniel Benetti, personal communication. 2012). Submergible cages have a much greater ability to withstand hurricanes and the swells and currents produced by them. Both Sea Stations (Benetti 2004) and Aquapods (Steve Page, personal communication, 2013) have survived hurricanes without losing fish so a certain level of hurricane risk is tolerable as long as the farm is set up for this. The Western Pacific basin supports a strong aquaculture industry despite the largest frequency of hurricanes in the world (NOAA Coastal Service Center 2013). Values below 0.05 (one storm every 20 years) were re-classified as 1.5. Values between 0.05 and 0.1 (less than one storm every 10 years) were re-classified as 1.4. Values between 0.1 and 0.25 (less than on storm every 4 years) were reclassified as 1.3. Values between 0.25 and 0.5 (less than one storm every other year) were classified as 1.1 and values between 0.5 and 1 (less than a storm per year) were classified as 1. All other values were given a score of 0.

Bathymetry is also difficult to quantify as a function of cost or benefit to a company. Certain depth are too shallow or too deep for the cages and these are simply unsuitable for cage aquaculture. Within this acceptable range, deeper sites with a larger water column have a higher ability to assimilate nutrients and more oxygen so they are more resistant to changes in chemistry. Shallower sites may be easier to work on and safer for divers. Neither of these factors converts easily to a cost, nor would the cost or benefit of that be dramatic compared to the other factors. As such depth within the acceptable range to deploy sea cages (25 to 70 m) were reclassified with a score of 1, with depths within above 30 m and within the recreational no-decompression SCUBA diving limit (40 m) were given a score of 1.2.

Proximity to shore represent a much more easily quantifiable cost. With tending vessels making regular trips to the site (daily or more for most Caribbean aquaculture farms although usually less for countries with more established industries) the fuel cost and the time paid to employees while they are being transported is significant. Farms have been sited up to 20 km offshore (Falconer *et al.* 2013), but beyond that distance the cost of travel can become prohibitive. Having farms further offshore can have advantages such as reduced interactions with other ocean users, less pollution from surface run off, and reduced thievery but these are small in comparison to fuel and extra labour costs. Sites within 3 km of land were given a rank of 1.5, sites within 5 km of land were given a rank of 1.4, sites within 10 km of land were given a rank of 1.2 and sites within 20 km of land were given a rank of 1. All sites beyond 20 km of land were given a rank of 0.

The reclassified rasters were multiplied together to produce a raster of graded site quality ranging from 1 to 9.2664. All the scores were divided by 9.2664 then multiplied by 10 to make the scale more comprehensive. Trends were examined with regards to size quality by total area and certain areas of interest were examined.

Results of the Analysis:

The results represent areas most suited to cobia culture. Many of these trends depend on oceanographic parameters associated with offshore aquaculture in general, but temperature, which is a strong determinant of growth rate and profitability, was heavily weighted and creates a preference for more southern sites. If species which prefer cooler water were assessed, sites in the Gulf of Mexico and The Bahamas would have scored better. It also must be noted that some included areas are not suitable aquaculture when considering socioeconomic and logistical factors. Cay Sal Bank, for example, has 56 sites around it but none of the islands on the bank are more than 2 km^2 and could not support any level of industry.

The sites were normally distributed by quality around a mean of 3.008. The most attractive site had a score of 6.993 although only one raster cell (4 km^2) had this score. This site was just north of Isla Bastimentos in the Bocas del Toro district of Panama. There were 18 sites with a score above 6 with an area of 108 km^2. These account for 0.36% of the identified suitable area. All but one of these were on the Caribbean coast of Costa Rica and Panama (figure 11) and these sites represented the closest areas to shore of larger clusters of sites (met the ‘within 3 km’ of shore criteria). Eighty-four sites scored between 5 and 6 making an area of 648 km^2. This represented 2.2% of the suitable area. These were primarily distributed along the Caribbean coast of Costa Rica and Panama as well, but there were three sites on the eastern site of the Yucatan Peninsula in

Mexico (including off the island of Cozumel) as well as one site off the island of Roätan in Honduras, one site off Jamaica, and one off St. Vincent island in St. Vincent and the Grenadines. The 282 sites which scored between 4 and 5 occupied 3,048 km^2 which represents 10.2% of the suitable aquaculture area. These occurred all throughout the study area but primarily in the Caribbean Sea and were less concentrated in the Gulf of Mexico or The Bahamas. The 668 sites which scored between 3 and 4 accounted for 9,484km^2 of area and 32.9% of the area suitable for aquaculture. These sites include the highest ranked sites found in US waters as well as many sites in The Bahamas and a few in the Gulf of Mexico. The largest collection of sites fell between a score of 2 and 3. The 685 sites in this range occupies 12,372 km^2 and 41.4% of the site area. Sites were distributed throughout the study area but particularly in The Bahamas and Lesser Antilles. The remaining 185 sites which scored between 1 and 2 occupied 3884 km^2 and 13.0% of the suitable area.

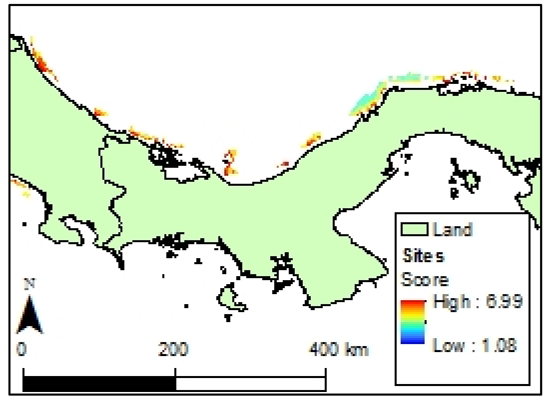

Figure 11: Aquaculture sites by quality score on the Caribbean coast of Costa Rica and Panama

These findings suggest that there is a large potential for offshore aquaculture growth in the Caribbean and to a less extant in The Bahamas and Gulf of Mexico. The Caribbean coast of Panama and Costa Rica represent the most promising area for development and is the most developed region already with Open Blue Sea Farms located there.

The most limiting factor in the study area is bathymetry as only 4.1% of the study area was ranked 1 or above. Suitable distances from shore represented only 5.7% of the study area so large extents were eliminated where these two small percentage areas did not overlap. This was particularly evident in the Gulf of Mexico where the slowly sloping bottom does not reach 25 m until further off shore than 20 km in many places (figure 12). Scores in the Gulf of Mexico were also hurt by a lower temperature often scoring 1 or 1.25. Some sites were eliminated by the critical low temperature.

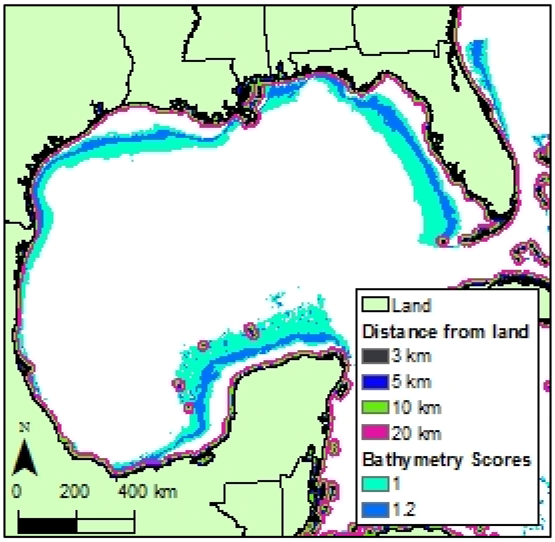

Figure 12: The Gulf of Mexico with the distance from shore and bathymetry score rasters shown.

The Bahamas had 3876 km^2 of area suitable for aquaculture but the average score was in the 2-3 range. This is largely a reflection of a cooler temperature than in the Caribbean as most Bahamian sites received a score of 1.25 for this parameter. Hurricane frequency also scored lower in The Bahamas than southern Caribbean. A species which shows strong growth in the 20 – 25 °C range would score very well there.

The Lesser Antilles had 3952 km^2 of suitable area with an average score in the 4 to 5 range. This represents a promising area for growth although concerns remain about demographic and logistical elements of site selection for many of these islands.

Extensions:

The site selection model would be most useful if monetary values could be assigned to each parameter range instead of scored values. Information from several stabilized fully operating farms, the relative improvement in fish growth, survival, and FCR as well as farm operational costs could be modeled as a function of each parameter. This would allow the parameters to be reclassified according to monetary benefit and the output raster to reflect profit margins or return on investment. Sufficient data to do this analysis with confidence does not yet exist.

Chapter IV

Conclusion

The economic analysis tool produced cost and revenue streams similar to those seen or projected by existing aquaculture farms in the Americas (Benetti, personal communication, 2013; Hoagland *et al*. 2005; Posadas and Bridger 2004). The example used in the model required an initial investment of \$3.27 million in the first year and \$8.74 million over 5 years but show an internal rate of return of 36% and net present value of \$17.62 million over the 10 years covered in the model. This represents an attractive investment to risk neutral investors with sufficient capital.

The site selection protocols found 29.9 thousand km^2 of suitable ocean for offshore aquaculture of cobia in the study area. The most attractive region was the Caribbean coast of Costa Rica and Panama with the highest ranked site at 6.99 located at 82.157211° W by 9.365561° N. The sites identified are all promising enough to warrant the investment in a site visits and follow up studies.

The economic model and site selection protocols can be modified and reanalyzed for different regions and different species very quickly which makes them ideal tools for early stage consulting.

The tropical marine aquaculture industry currently sits in a "chicken and the egg" type situation where investors are hesitant to join the marine industry in this region due to poor legislative framework for siting and operation, limited technology for production and grow-out and a lack of comparable successful firms. At the same time, efforts to resolve these problems are not receiving sufficient attention since the industry is not yet generating large profits nor represented by many participants. Advancing either side of this equation would be beneficial to the development and maturation of the industry. The models proposed here would encourage potential investors to engage in feasibility stage consulting, the first step towards starting an aquaculture operation. The economic model removes some of the uncertainty with regards to level of investment, payoff period, and the value of the investment while also providing insights on how to design and run the farm to optimize profits. The format of the model allows investors to consult with parties who have experience with the early stages of these businesses and can provide accurate estimates of costs from real examples which will improve the confidence in the model.

The site selection protocols provide an essential piece of early stage planning; evaluating suitability of sites in the area of interest. Many aquaculture investors have specific regions of interest which may or may not be suitable for aquaculture. The site selection protocols will confirm that suitable sites do exist in a given area and also give an indication of the quality of those sites. This can be done before any time and resources are spent on site visits.

Both of these tools will be used by consultants to provide sufficient information for investors to make informed decisions. The purpose is not to make appealing looking business plans with which to approach investors with but rather to accurately evaluate a proposed plan. By having tools like these widely available in the industry, investors with little experience in aquaculture can see the risks and rewards easily which will facilitate entrance into the fish farming business.

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