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Developing A Pilot Quota-based Fishery Management System For Fujian's *Portunus* Crab Fishery

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Abstract

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China's Ecological Civilization vision advances the sustainable development of the coastal marine fisheries in the nation's policy agenda(Cao et al., 2017). As one of the main fisheries reform measures, a quota-based fisheries program has recently been developed to explore best management practices and generalizable experience that fits into China's unique context. However, insufficient knowledge of the fishery's ecological, social, cultural, and institutional dimensions has compromised the effectiveness of this approach to fisheries management. The thesis identifies the Fujian's *Portunus* crab pilot program (PCPP) as a case study and develops a heuristic model of its natural-human-management sub-systems to advise future implementation of the management system. The model is developed from qualitative data collected from stakeholder interviews, literature reviews, field investigations, and applied fisheries simulation

models to understand its ecological, socioeconomic, community, and institutional characteristics. A multidimensional sustainability assessment framework is established to scope PCPP's fisheries system characteristics and examine a) the degree of fulfillment on each indicator with respect to their impacts on PCPP's fisheries sustainability, and b) the degree of understanding with respect to stakeholders' knowledge and data availability at current stage (Charles, 2001; Pitcher & Preikshot, 2001). A theoretical PCPP fishery is established using the size-structured discrete-time model and Data-limited Toolkit to provide preliminary management strategies evaluations for the PCPP (Schnute, 1987; Carruthers & Hordyk, 2018a).

Six major challenges to the success of current practices of *Portunus* crab management are identified. They include: no universal understanding for stakeholders with respect to the definition of a quota-based fisheries management system; the incompatibility problems between China's existing legislative framework and PCPP management plan; misaligned stakeholder interests that challenge the scientific principles of implementing catch limits in PCPP; inadequate management capacity to support the current policy practices; the oversimplification of multispecies issues in PCPP management considerations; institutional limitations with respect to stakeholders' unbalanced participation in PCPP initiative. The framework identifies that a) the deficiencies in ecological dimension limits science capacity of TAC system and deficiencies, b) the deficiencies in equity and IUU fishing compromises the compliance and performance, and c) the deficiencies in socioeconomic dimension provide limited knowledge ground on the fisheries efficiency improvement regarding social and economic benefits as the management objectives. The preliminary model analysis identifies effort control as the most advantaged management strategy based on the PCPP's available data. The model also examines yield per recruit,

spawning biomass per recruitment, biological reference points, and the relationship between average yield and exploitation rates to provide implications on PCPP's fisheries management. Based on the systematic analysis of the Fujian swimming crab fishery, the study proposes the following scenarios in PCPP's future management implementation, including 1) developing an adaptative management planning grounded in the multifaceted aspects of the fishery system, 2) establishing new institutional mechanism for equal stakeholder participation in the decision-making process, 3) strengthening science-based fisheries management capacity toward a well-managed direction, 4) providing legal authority to enforce PCPP new management measures, 5) building consensus with consideration of stakeholder knowledge ground and alignment of interests, 6) understanding the ecological complexities of the PCPP fishery.

TABLE OF CONTENTS

List of Figures iii

List of Tables iv

Chapter 1. Introduction AND METHODS 6

1.1 Introduction 6

1.2 Methods 8

Chapter 2. Fishery System Approach 10

2.1 The Ecological sub-system 10

2.1.1 The Biophysical Environment and The Ecosystem 10

2.1.2 The Crabs 13

2.2 The Human Sub-system 15

2.2.1 Stakeholder Perceptions 15

2.2.2 Fishery Improvement Project Investigation 19

2.3 The Management Sub-system 20

2.3.1 Introduction 20

2.3.2 China's National Marine Fishery Management System 21

2.3.3 Subnational Fisheries Regulations in Fujian's PCPP 22

2.3.4 Challenges Under the PCPP Management Plan 27

2.4 Review of *Portunus* Crab Fisheries Worldwide 32

2.4.1 Philippine 33

2.4.2 Indonesia 34

2.4.3 Taiwan (China) 35

2.4.4 Australia 35

Chapter 3. A Multidimensional Participatory Approach to Assessment Sustainability on PCPP 37

3.1 Ecological Sustainability Assessment 39

3.2 Technology Sustainability Assessment 45

3.3 Socioeconomic Sustainability Assessment 46

3.4 Ethical Sustainability Assessment 50

3.5 Institutional Sustainability Assessment 52

Chapter 4. Management Practices Based on Fish Biological Modelling 54

4.1 Parameter Determination 57

4.2 Estimations of *Portunus* crab Yield Per Recruit (YPR), Spawning Biomass Per Recruit (SBPR), and Biological Reference Points 58

4.3 Alternative Harvest Strategies to the PCPP – an example of fixed harvest rate 63

4.4 Preliminary PCPP Management Strategies Evaluation 65

Chapter 5. Conclusions 66

Chapter 6. Future Work 71

Bibliography 73

Appendix A- Interviewees 82

Appendix B – Interview Template 83

Appendix C – Definitions for management procedures 84

LIST OF FIGURES

Figure 1.1. Increase in the cost of p

Figure 1: China's coastal fishing grids and designated jurisdiction (red square) for the PCPP ("China - Korea fisheries agreement," Accessed by June 14, 2019). 12

Figure 2: The geographic map of *Portunus pelagicus* (FAO Fisheries & Aquaculture, 2013b) 14

Figure 3: fishery improvement project geographic scope covers Zhao'An, Dongshan, and Longhai in Great Zhangzhou area. 20

Figure 4: PCPP administrative region is shown in No. 282 and 283 fishing grids..... 23

Figure 5: Conceptual map of PCPP Management Structure..... 24

Figure 6: *Portunus* crab production in Fujian Province. Data extracted from China's Fisheries Yearbook Statistics since 1986. 40

Figure 7: Historical Statistics of China's Portunidae Product Export to U.S. Market (National Marine Fisheries Service, 2019) 50

Figure 8: Catch per unit effort (CPUE) of Red Swimming Crab (*Portunus hannii*), other *Portunus* crabs, and other non-*Portunus* crabs based on a single-trawl survey 56

Figure 9: Vulnerability and Maturity Curve. Age is based on month. 60

Figure 10: Yield per Recruit in relation to harvest rate 61

Figure 11: Spawning Biomass per Recruit in relation to harvest rate 61

Figure 12: Long-term Yield in relation to harvest rate 62

Figure 13: Total yield in relation to harvest rate under steepness 0.5, 0.7, and 0.9..... 62

Figure 14: average yield in relationship to monthly harvest rate..... 65

Figure 15: the assessment results of multidimensional participatory framework..... 69

Figure 16: tradeoffs among different fisheries management strategies 70

ower quality problems in the United States [1]. .....**Error! Bookmark not defined.**

LIST OF TABLES

Table 1: The responsibilities and connections of each group of stakeholders in the PCPP.15
Table 2: The framework includes five dimensions and indicators for China's PCPP system. 39
Table 3: Parameters for Model 1 57
Table 4: Parameters for Model 2 57
Table 5: Fishing biological reference points with steepness 0.5, 0.7, and 0.9..... 62
Table 7: Commodities, implications, and sources are tabulated..... 66
Table 8: Challenges in PCPP Subsystems 68

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Chapter 1. INTRODUCTION AND METHODS

1.1 INTRODUCTION

As the world's top fish producer and consumer, China has a significant influence in the global fisheries affairs (FAO, 2011). China's marine fisheries have witnessed an unprecedented reform since the overarching framework of Ecological Civilization has been put forward in the nation's development agenda in 2012. China's Ecological Civilization has prioritized the nation's environmental governance in sustainability of natural resource management, including its marine fisheries resource.

To implement this framework in the marine fisheries domain, the State Council has published the guiding ideology of improving the existing marine fisheries management system and promoting a more sustainable and healthy marine fisheries (State Council of People's Republic of China, 2013). In the subsequent years, this guiding ideology has led to a series of innovative management reforms within China's marine fisheries domain. In 2017, the Ministry of Agriculture and Rural Affairs of the People's Republic of China (MoA) put forward the implementation of a new marine fisheries management system regarding domestic fishing vessel control and quantitative marine fisheries resource management (the Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2017). Since 2017, MoA has approved the establishment of China's first-tier quota-based fisheries management pilot program in five coastal provinces, including Fujian. In Fujian Province, a *Portunus* crab pilot program (PCPP) was established in 2018. The thesis reviews the current policy implementation in PCPP. It should be noticeable that PCPP is an ongoing program with the willingness to improve PCPP's future management practices based on the solutions of identified problem in its first-year pioneering work.

Based on a literature review and qualitative interviews, the thesis identifies two major management objectives in PCPP. First, PCPP intends to pursue fisheries sustainability via a series of innovative regulations under the quota-based fisheries system. China's paradigm shift in marine fisheries has elevated ecological considerations in its domestic fisheries management in China's domestic fisheries 13th Five-Year Management Plan (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2016). This shift advances the process of cementing policy ideology into the subnational fisheries management plan. PCPP is one of China's demonstration programs that intend to offer a referable sustainable fisheries system to other domestic fisheries. Second, PCPP aims to explore existing available quota-based fisheries management measures based on the unique social, ecological, institutional, and community characteristics in *Portunus* crab fishery system. Currently, the total allowable catch (TAC) is established in PCPP to regulate all targeted *Portunus* crabs as a single "stock".

The roadmap in this thesis is the process of developing PCPP scenarios via challenges analysis, a systematic fisheries sustainability appraisal, and evaluation of alternative management strategies. Three research approaches adopted, including a fishery system approach to understand the characteristics of ecological, human, management subsystems in the PCPP (Charles, 2001), a multidimensional participatory appraisal framework to define and systematically assess PCPP's sustainability (T. Pitcher & Preikshot, 2001), and a preliminary management strategies evaluation to identify the most advantaged management strategy for PCPP (Schnute, 1987; Carruthers & Hordyk, 2018). The management practices in *Portunus* crab fisheries worldwide are also reviewed. The synthesis of research results is used to advance the understanding PCPP's management system, identify challenges and deficiencies, and develop recommendations and scenarios on the future improvement.

1.2 METHODS

The overarching framework of this study is substantially based on Charles' Sustainable Fishery System heuristic approach (Charles, 2001). In order to systematically understand China's *Portunus* fishery pilot program as well as other comparable fishery systems, Chapter 2 examines the fishery system as an ecological sub-system, a human sub-system, and a management sub-system. The ecological sub-system focuses on the fishery's biophysical environment, targeted stock(s), and the ecosystem. The human sub-system draws on the synthesis of stakeholder perceptions, qualitative interview analysis, literature reviews regarding the socio-economic aspects of *Portunus* crab fishery. The management sub-system focuses on China's national marine fisheries management and subnational PCPP management plan in Fujian Province.

Human subject research (HSR) is applied to obtain knowledge from human-dimension sources to model PCPP's current state and obtain stakeholder perceptions of PCPP's management practices (Wengraf, 2001). HSR was approved by University of Washington Institutional Review Board (IRB) review [1]on June 20, 2018.

The study used a snowball sampling method for interviewee recruitment and a semi-structured technique to conduct the qualitative interviews from June to September 2018 (Biernacki & Waldorf, 1981; Wengraf, 2001). Nineteen interviews were conducted and the interviewees are categorized into six groups based on their professional identities in the *Portunus* crab fishery system, including 1) two government officers, 2) two fishery managers, 3) two *Portunus* fishery industry associated employees, 4) four fishery academic experts from provincial research institutions and universities, 5) four *Portunus* fishery fisherfolks, and 6) five staff in environmental non-governmental organizations. The interviewees are represented with a coded professional

[1] The thesis's IRB approval ID is STUDY00004229.

identity and an informant number, including Government (G1, G2), Manager (M1, M2), Industry (I1, I2), Academia (A1, A2, A3, A4), Fisherfolk (F1, F2, F3, F4), and NGO (N1, N2, N3, N4, N5 (Appendix 1).

To ensure the eligibility of qualified interview subjects in the PCPP, the participation inclusion of stakeholders applied specific criteria and characteristics. The general characteristics require the subjects to be the fishery-relevant stakeholders in the *Portunus* crab fishery pilot program. The design of interview recruitment aims to obtain diverse stakeholder perceptions from a variety of professional identified described above. Individually, all subjects should be adults (age greater than or equal to 22 years old), in good mental competence, and willingness to commit to the participation of this study. The participation inclusion criteria are 1) the subject is involved in PCPP-related professional commitment, 2) the subject has been engaged in South Fujian and Taiwan *Portunus* crab fishery partially or fully in his/her enterprise, 3) the subject has enough experience or knowledge related to *Portunus* crab fishery and PCPP management system.

With the goal of seeking implications of applicable fisheries management practices on *Portunus* crab fisheries elsewhere, the thesis employs a comparative review of *Portunus* crab fisheries management practices in four jurisdictions using desktop-based literature research to understand the rationales and performances of the existing and perspective management practices in *Portunus* crab fisheries worldwide (Baumeister & Leary, 1997; Marchal et al., 2016). The criteria used to select cases are whether these jurisdictions have implemented certain management strategies on their *Portunus* crab fisheries. The study highlights the implications from Australian *Portunus* crab fisheries management given its implemented quota-based fisheries management matches China's current reforms in reforming its marine fisheries toward the quota system. Implications from these cases are extracted for the reference to China's PCPP management measures.

In Chapter 3, a multidimensional participatory appraisal assessment modified from the sustainable fishery system and Rapfish frameworks is applied to qualitatively analyze PCPP's performances and knowledge deficiency with respect to the indicators of sustainability (Charles, 2001; Mendoza & Prabhu, 2003; T. J. Pitcher et al., 2013). The framework synthesizes stakeholder's perceptions and available literature review data to 1) explore dimensions, indicators, and operating definitions regarding sustainability in China's marine fisheries arena, 2) qualitatively assess the current degree of contributions with respect to PCPP's sustainability, and 3) qualitatively assess the current knowledge status in PCPP fisheries system.

A preliminary assessment regarding *Portunus* crab biological and fisheries characteristics using fisheries modelling approach is applied in Chapter 4. The thesis develops a theoretical PCPP fishery using available data to evaluate management strategies. The modelling outputs are used to provide preliminary implications that are applicable for PCPP fisheries management. Given the current limitations. The model simulations intend to tutor the improvement of PCPP's management practices in the next stage. The applications of more complex models (i.e. ecosystem-based modelling and multispecies modelling) are expected in the future work with more available data in Fujian *Portunus* crab fisheries.

Chapter 2. FISHERY SYSTEM APPROACH

2.1 THE ECOLOGICAL SUB-SYSTEM

2.1.1 *The Biophysical Environment and The Ecosystem*

The geographic jurisdiction of PCPP is designated in No. 282 and No. 283 fishing grids in the South Fujian-Taiwan Bank Fishing Ground (22° 00′ ~ 24° 30′ N, 117° 30′ ~ 120° 45′ E)

(Figure 1). Its waters lie in the subtropical zone and between the South China Sea and the East China Sea. The Taiwan-Kuroshio Current and subtropical monsoon climate commonly occurring in summer are identified as two major environmental processes that influence the biophysical environment in the waters (F. Chen, 2006). Due to the intrusion of Kuroshio current and Southwest monsoon in summer, strong coastal upwelling brings colder and nutrient-abundant deep-sea waters into the surface (He, 1988). Studies about South Fujian-Taiwan upper-level waters observed the combination of low temperature and high salinity in the South Fujian and Taiwan shoaling waters from June to September and the high-salinity hotspot from October to March next year, which proves the existence of upwelling currents in the South Fujian coast (Jinquan Chen, Fu, & Li, 1982). There is a general recognition of characteristics of this area with respect to nutrient abundance, high primary productivity, high energy transmission, and short carbon turnaround time, which supports a variety of tropical and subtropical finfish and crustaceans in South Fujian-Taiwan Fishing Ground (Jinquan Chen et al., 1982; He, 1988; Liu, Chen, Huang, & Zhang, 2011; Xiao, 2003).

Figure 1: China's coastal fishing grids and designated jurisdiction (red square) for the PCPP ("China - Korea fisheries agreement," Accessed by June 14, 2019).

Climate change (e.g. ENSO events) also provides environmental variability in associated with the inter-annual fluctuation of pelagic fish abundance. ENSO is the recurring climate pattern occurring in tropical and subtropical Pacific areas. Studies have revealed the oceanographic characteristics during ENSO are that the significant increase of the flux of Kuroshio Current and subtropical high before ENSO, which contributes to the occurrence of stronger upwelling currents and high sea surface temperature in South Fujian-Taiwan coast (He, 1995; Wu, Qiu, & Yang, 2000; Yan, 2006). High-nutrient deep-sea waters and subtropical high weather boost the growth of zooplankton, which increases the abundance of pelagic fish population with abundant preys. During the La Nina phase (i.e., 1973-1974; 1975-1976; 1998-1999 and 1999 -2000 years), water temperature in East China was observed to decrease (Yuan, Liu, Cheng, & Tian, 2017). While there has little evidence regarding La Nina's impact on *Portunus* crab abundance, colder water temperature is an adverse

environmental factor for tropical crab species like *Portunus* crab (Campbell, 2017; Yuan et al., 2017).

2.1.2 *The Crabs*

Portunus is the genus name for crabs under the family of *Portunidae* in the scientific classification (Weber, 1795; Rafinesque, 1815). Crabs in *Portunidae* family are commonly referred as swimming crabs or *Portunid* crab, which are characterized with their flattened paddles on the last pair of legs used for swimming (Davie, 2002). The genera in *Portunidae* family include *Portunus*, *Scylla*, and *Charybdis*. In China's fisheries statistics, the category of *Portunus* crab considers all available crab within the genera of *Portunus*, Scylla, and Charybdis as one single "stock". The common *Portunus* crab species in PCPP pilot waters include but not limited to *Portunus tribuberculatus, Portunus hannii, Portunus sanguinolentus, Portunus pelagicus, Charybdis natator, Charybdis acuta, Dromia dehaani, Calappa lophos, Charybdis japonica, Charybdis feriatus, Scylla paramamosain, Calappa philargius*. Some of *Portunus* crab species (i.e. *Portunus pelagicus*) has have been well studied considering their economic importance in local or regional fishery production.

Portunus crabs are widely distributed in Indian and Pacific Oceans. There are two *Portunus* species well profiled in FAO: *Portunus pelagicus* and *Portunus trituberculatus* (FAO Fisheries & Aquaculture, 2013). Both species have a similar geographical distribution from Southeast and East Asia to Australia. Their common morphological characteristics is the 9 nine teeth on each anterolateral margin with the most external one much larger than the preceding. They live in shallow waters (less than 50 meters) with sandy and muddy sea bottom. Their distribution is shown in Figure 2.

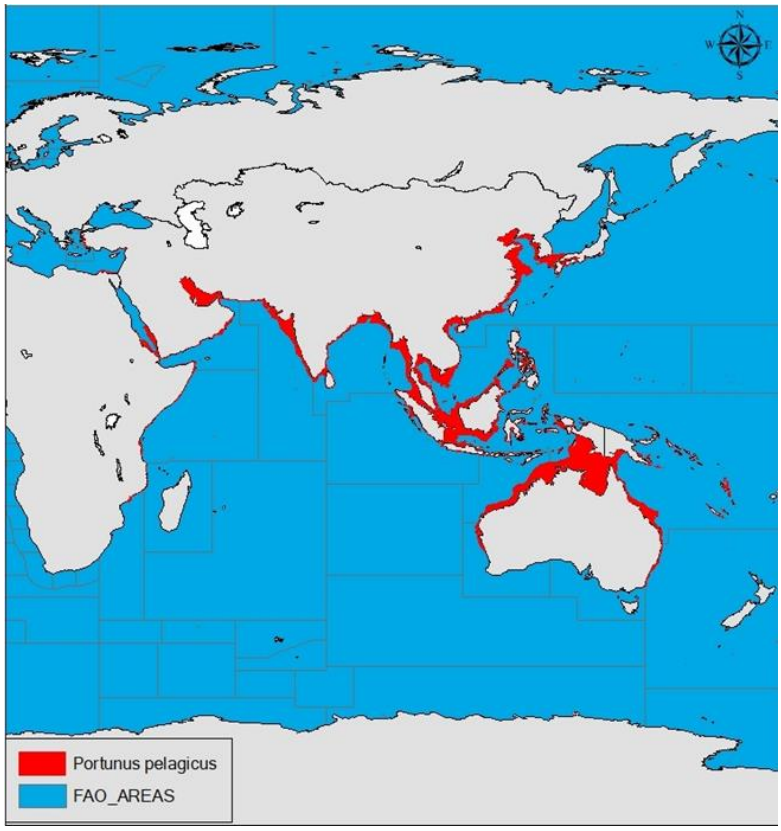

Figure 2: The geographic map of *Portunus pelagicus* (FAO Fisheries & Aquaculture, 2013b)

On the South Fujian – Taiwan Fishing Ground, *Portunus* crabs have been recognized for their economic value for decades. Before the 1980s, the medium-large size *Portunus* crab species such as *Portunus pelagicus, Portunus trituberculatus,* and *Portunus sanguinolentus* were the main catch in the local fishery. After the 1980s, small-size *Portunus* crab species like *Portunus hannii* witnessed the significant increase with respect to their economic values and the corresponding fishing efforts due to the declining resource of traditional medium and large *Portunus* crabs (Zhang, 1997). However, crab fisheries in South Fujian -Taiwan Fishing Ground have provided the dominant proportion of provincial marine crab landings (i.e., 80% in 1990s with 4.5 to 5 tons) (P. Huang, 1998). A recent study revealed that there were 28 *Portunid* crab species in *Portunidae* family, which account for the largest proportion of the 94 sampled crab species from the South

Fujian – Taiwan Fishing Ground (Chang-chun Shen, Chao, Liu, Xu, & Ye, 2014). Most of sampled crabs are tropical and subtropical warm water species.

With respect to the targeted *Portunus* crab species for the purpose of implementing the pilot quota-based management program, there are 4 *Portunus* crab species included in the *Portunus* pilot program, including Japanese Blue Crab (*Portunus trituberculatus*), Red-spotted Swimming Crab (*Portunus sanguinolentus*), Red Swimming Crab (*Portunus hannii*), and Blue Swimming Crab (*Portunus pelagicus*). The common characteristics of the four *Portunus* species above is that they inhabiting the in the shallow seas and are subject to travel net, pot funnel, and gillnet gears (Chang-chun Shen et al., 2014). Given that medium and small-size crabs now are dominant in South Fujian waters, *Portunus hannii* is distinguished among three other traditional economic species because of its robust resource abundance and increasing economic values.

2.2 THE HUMAN SUB-SYSTEM

2.2.1 *Stakeholder Perceptions*

Based on the criteria described in the method, the study identifies six groups of stakeholders with respect to their participation in *Portunus* crab pilot program, i.e., fisherfolks designated with exclusive rights in *Portunus* crab pilot program (F), provincial government officers (G), fishery managers (M), *Portunus* crab fishery industry associated employees (I), fishery experts from universities and research institutions (A), and environmental non-governmental organization staff members (N). Their connections with Portunus crab pilot program are illustrated (Table 1).

Table 1: The responsibilities and connections of each group of stakeholders in the PCPP.

Groups	Responsibilities	Connection
Government	- Develop policy guideline and affiliated regulations	Policy Making

	- Determine catch limit in *Portunus* pilot program - Provide fishery management plan	
Manager	- Supervise vessel operation and fishery logbooks - Monitor vessel position - Implement fishery enforcement - Determine eligible pot fishers - Designate sites for fixed landing transaction - Issue exclusive fishing licenses	Policy Implementation, Supervision and Monitoring, and Enforcement
Fisherfolk	- Maintain *Portunus* fishing operation - Report fishery data through logbooks - Meet *Portunus* pilot program requirements	Management Subject
Academia	- Determine total allowable catch based on research - Assist policy and regulation design - Provide evaluation report	Scientific Input
Industry	- Influenced by *Portunus* crab supply chain - Facilitate fishery research and policy practices	Financial Interest Related
NGO	- Provide capacity support - Conduct fishery improvement project	Capacity Support

In terms of interview results, the study examines the following aspects regarding the level of interviewees' understanding on PCPP. They are 1) definitions of quota-based fisheries management, 2) perceptions of the difficulties, 3) expected scenarios for PCPP's future development based on the interviewee's subjective evaluation criteria.

Interviewees in the academia group generally have a deeper understanding of the definition of quota-based fisheries management than other groups. A1 and A3 claimed quota-based fisheries management system should has a "precise and rational" quota setting in catch and highlights the importance of good compliance for fishers. A2 identified China's current quota-based fisheries management as the output control via catch limits. It was admitted that difference exists in the policy implementation between central government and provincial government. To be more specific, quota management can also include input control tactics (i.e., quota for fishing gear) from the perspective of central government in the meanwhile provincial governments generally adopt quota-based fisheries management through catch limits [A2]. A4 claims that China's quota-based fisheries management is at its very beginning stage and TAC is currently determined based on historical catch, survey data, social factors, and fishers' perceptions.

For interviewees in the NGO group, their understanding of quota-based fisheries management generally aligns with FAO and international definitions. N1 thought China's quota-based fisheries management is implemented through number or quota limit and advocated its adjustments for its applicability in China's fisheries context. N3 claimed quota-based fisheries management is one of the fisheries management measures among multiple fisheries management tools. In China's fisheries context, quota-based fisheries management is the system that ultimately allocates quota on vessels [N3]. For interviewees in the government group, G1 claimed that quota-based fisheries management is the integration of total allowable catch and supplementary regulations. G2 claimed a susceptible standpoint regarding PCPP's feasibility at current stage but G2 indicated that it is a necessary step to overcome difficulties in marine fisheries reform. For interviewees in fisherfolk and industry groups, the study identified a relatively limited understanding of the definition of quota-based fisheries management.

For interviewees in the manager group, M1 expressed more interest in tackling practical challenges and regarded these solutions as the China-featured interpretation of quota-based fisheries management. The practical challenges concerned by M1 and M2 include but not limited to 1) limitations of implementing quota-based fisheries management regulations to eligible pot vessels beyond PCPP pilot waters; 2) the authenticity and format of fisheries logbook; 3) illegal, unreported, and unregulated fishing behaviors in PCPP pilot waters; and 4) enforcement limitation in overlapping fishing zone between fishing license system and PCPP pilot waters that permits licensed fishing vessels from other counties and cities to operate fishing practices. M2 highlighted their responsibilities in ensuring legal fishing and unsafe fishing behaviors (i.e., fishing before and after the monsoons). Although M2 strongly advocated the implementation of quota-based fisheries management, M2 admitted its difficulties in implementing this policy and expressed confuses in China's subsidies in fuel costs and investment in fisheries infrastructure.

Regarding interviewee's judgment of the success of PCPP, interviewees in the government, academia, and manager groups focus on the increasing compliance for fishers on introduced PCPP regulations [G1, G2, A1, A3, A4, M1, M2], a more robust management mechanism regarding credible data collection, quota allocation, fisheries monitoring, and administrative inspection [G1, G2, A1, A3, M1, M2], and socio-ecological management objective regarding *Portunus* crab biomass, fisherfolk livelihood, and market stability [A1, A2, A4]. The expected expectations of industry interviewees closely concern with their business operation. Currently, I1, I2 and N1 held a neutral standpoint toward PCPP given the increasing pressure from international market demand and little evidence of PCPP's negative impacts on reducing *Portunus* crab supply. In terms of interviewees in the fisherfolk group, F1 and F2 complained the fishing competition from trawl vessels in other cities and expected PCPP to guarantee their priority in their fishing grounds. F3

and F4 concerned about PCPP's impacts on their income. Given relatively low *Portunus* crab production in the recent years, labor expenses depend on bank loans [F3, F4]. Two interviewees in NGO group claimed their expectations in China's quota-based pilot programs include the identification of feasible management practices [N1, N2] and the development of institutional mechanism to collaboratively implement the project [N2]. The U.S. Regional Fisheries Management Councils management system is identified as an example for China's marine fisheries reform [N2, N3]. Another two interviewees indicated NGO's role as the platform for domestic and international fisheries organizations and highlighted NGO's role in helping China's marine fisheries capacity building [N2, N4].

2.2.2 *Fishery Improvement Project Investigation*

Although PCPP develops harvest regulations for its pilot vessels, it does not necessarily include vessels' roles in the *Portunus* crab fisheries business into its management plan. A fishery improvement project (FIP) was launched simultaneously with PCPP regarding the socioeconomic aspects of China Fujian Zhangzhou red swimming crab bottom trawl and pot/trap fisheries. The thesis analyzed FIP preliminary investigation to identify human-dimension characteristics of *Portunus* crab fisheries. It should be noted that this FIP is not part of PCPP management plan. Despite its socioeconomic assessment results in Chapter 3, the thesis will not discuss it in detail.

FIP report recognizes the connectivity of the Great Zhangzhou area because of the geographical adjacency to *Portunus* crab fishing ground and area-level *Portunus* fisheries industrial integration including *Portunus* crab processing, distribution, export, and so on (Figure 3). For local fishing vessels, the owners independently market their harvested crabs to local seafood wholesalers and processing enterprises (Qing, 2017). Many local processing enterprises choose to contract with crab fisherfolks to establish their stable crab resources supply channels via offering fisherfolks

prepaid deposit and cash allowance while other non-local ones rely on wholesale middleman (Qing, 2017).

As *Portunus* crab increasingly becomes economic products to international markets like United States, the sustainability of *Portunus* crab fisheries becomes a concerned not only by for China's PCPP fisheries authorities but also for a broader group of industry and NGO stakeholders domestically and internationally.

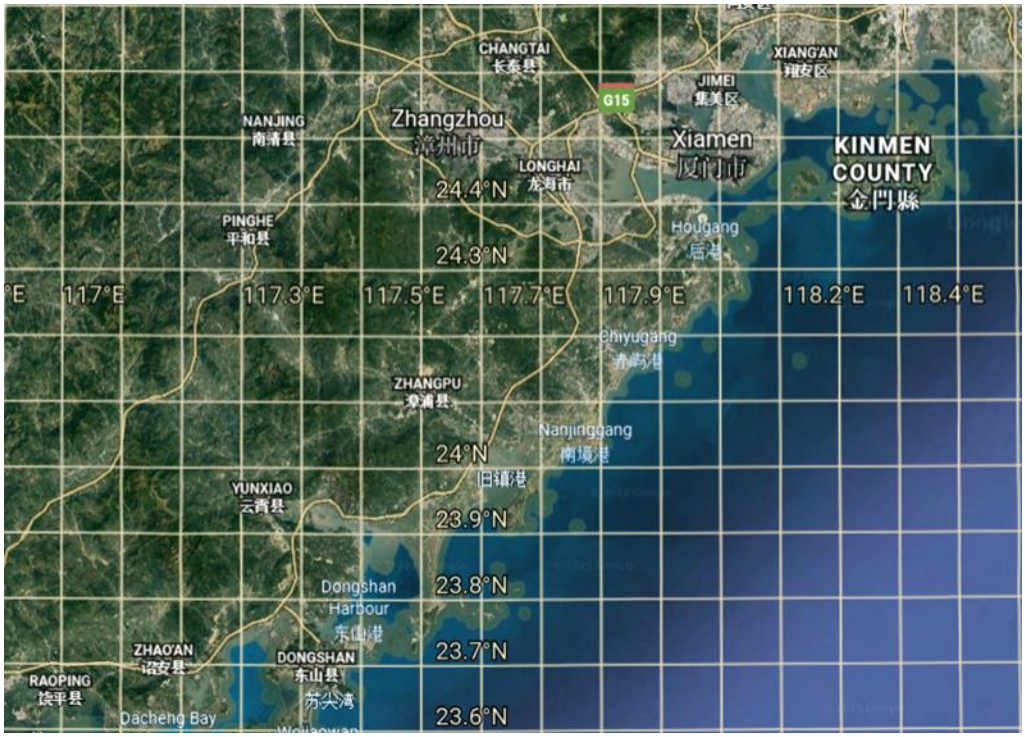

Figure 3: fishery improvement project geographic scope covers Zhao'An, Dongshan, and Longhai in Great Zhangzhou area.

2.3 THE MANAGEMENT SUB-SYSTEM

2.3.1 *Introduction*

The fisherfolks eligible to participate in the PCPP are simultaneously subject to China's national marine fisheries laws and regulations as well as *Portunus* fishery management plan. However, both fishery managers and fisherfolks claim it is challenging to ensure exclusive fishing operation

within the pilot waters [F1, F2, F3, F4, M1, M2]. To be more specific, fishing vessels registered in other counties and cities may enter the pilot waters to operate fishing without the restriction of *Portunus* quota-based management. Thus, the study reviews China's current marine fisheries legislative framework on a national and subnational level in order to understand the legal constrains of achieving exclusive fishing rights from the perspective of law and regulations.

2.3.2 *China's National Marine Fishery Management System*

The overarching framework in China's fisheries management is primarily based on Fisheries Law of People's Republic of China (Huang & Tang, 2010). A hierarchical fisheries legislation is established to implement various grades of fisheries laws and regulations from national level to subnational level. In this legislative structure, Fisheries Law of People's Republic of China has a highest superiority with respect to its legal authority because it originates with China's Constitution. Under the premise of being consistent with the Constitution and Fisheries Law of People's Republic of China, there are a series of national and subnational fisheries laws, regulations, and rules being developed and published as the legislative foundation of China's fisheries management system. They include a broad coverage of various aspects in China's fisheries, roughly including fisheries production management, fisheries resource conservation, fisheries water environmental protection, fisheries vessel management, fisheries port management, distant water fisheries management, fisheries management concerning foreign affairs, supervision and management of fisheries administration (Huang & Tang, 2010; Huang & He, 2019).

Recently, the MoA has launched the initiative to steer China's capture fisheries management toward the total catch control of fisheries resources (Cao et al., 2017). It leads to the establishment of five China's quota-based pilot program in five coastal provinces to explore feasible management practices. Differences may exist in each pilot program with respect to policy implementation and

fisheries characteristics, management tactics in pilot programs are generally catch limits. In terms of China's hierarchical fisheries management structure, PCPP management plan is a subnational fisheries regulation that is administratively enforced in Fujian's provincial waters. However, it has inferior legislative authority compared to national fisheries laws and regulations. There are currently few existing legislative clauses that can invoked to support PCPP articles.

2.3.3 *Subnational Fisheries Regulations in Fujian's PCPP*

The establishment of PCPP is based on pilot water designation and fish stock identification. From the geographical aspect, PCPP is a designated administrative region in South Fujian's province waters that explores and implements quota-based fisheries management regulations on fishing practices within its jurisdiction. 5 points (A (118° 04′ 1.8′′ E 24° 30′ 00′′ N), B (119° 00′ 00′′ E 24° 30′ 00′′ N), C (119° 00′ 00′′ E 24° 22′ 30′′ N), D (118° 30′ 00′′ E 24° 00′ 00′′ N), E (117° 49′ 44′′ E 24° 00′ 00′′ N)) encircle the whole PCPP region except for Taiwan's Jinmen water (Figure 4). In its initial year, a group of licensed pot vessels is assigned with PCPP eligibility as an interim measure to scope a portion of resource users into PCPP. The selected process for vessel eligibility in PCPP is the negotiation outcome of PCPP working group in consideration of a feasible coverage of implementing quota-based fisheries management measures with limited management capacity [G1, A1]. In other words, PCPP implements quota-based fisheries management measures to eligible pot vessels for their fishing practices in PCPP jurisdiction. From the biological aspect, PCPP identifies all available *Portunus* crab species in South Fujian and Taiwan fishing ground for their robustness under current fishing pressure, and economic significance. PCPP manages these *Portunus* crab species as a single fish "stock" in align with China's fisheries statistics. The eligible pot vessels are licensed in

Great Zhangzhou area, where is believed to be the *Portunus* crab processing and distribution center in China given its significant proportion of *Portunus* crab export volume to U.S. market (S. Wang, Drugan, Fang, Lincoln, & Chen, 2017).

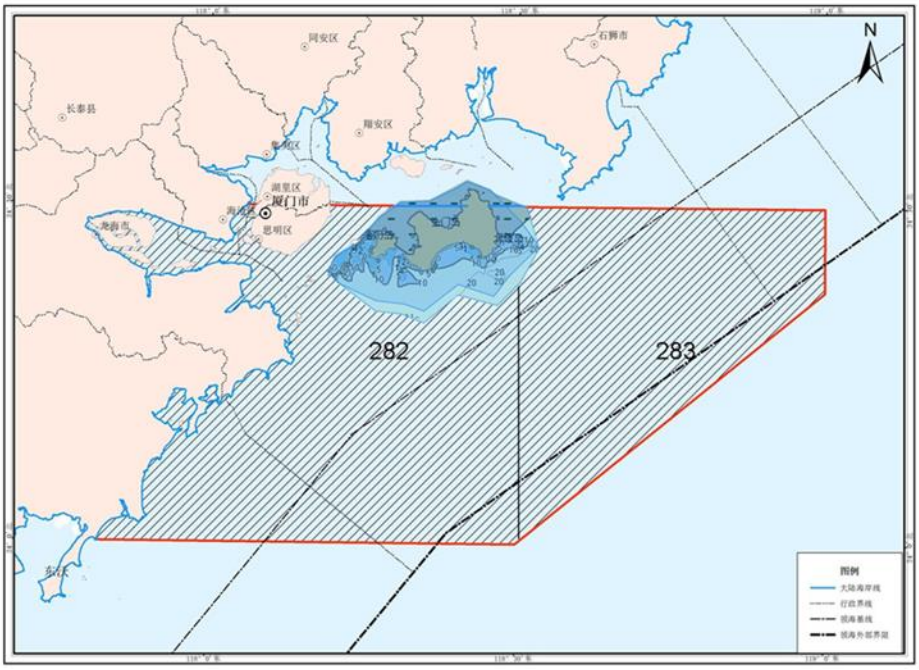

Figure 4: PCPP administrative region is shown in No. 282 and 283 fishing grids.

In terms of the specifications for determining the total allowable harvest level, two criteria have been applied to set the initial total allowable catch.

- Integrating social-economic factors with the historical catches to determine the maximum sustainable yield (MSY) as the means of catch limits for total *Portunus* crab harvest in PCPP jurisdiction.
- Initial total allowable catch (TAC) is 90% MSY based on the precautionary principle due to inadequate knowledge and uncertainty of *Portunus* crab population variance.

- The precautionary principle in PCPP management plan develops TAC based on 90% MSY in PCPP jurisdiction and sets the catch limits as 95% TAC considering the uncertainties of *Portunus* crab population assessment, multiple species interactions, policy implementation error, and environmental variances.

A hierarchical PCPP management system consists of an operational management dimension and a monitoring dimension (Figure 5). Catch quota is established as a means of limiting total Portunus crab harvest within PCPP waters. To ensure the quota accountability only for pilot vessels within PCPP waters, exclusive fishing permits, fixed landing and transaction management, and fisheries logbook statistics system are implemented. The compliance of these regulations and fisheries data authenticity reply on monitoring and enforcement.

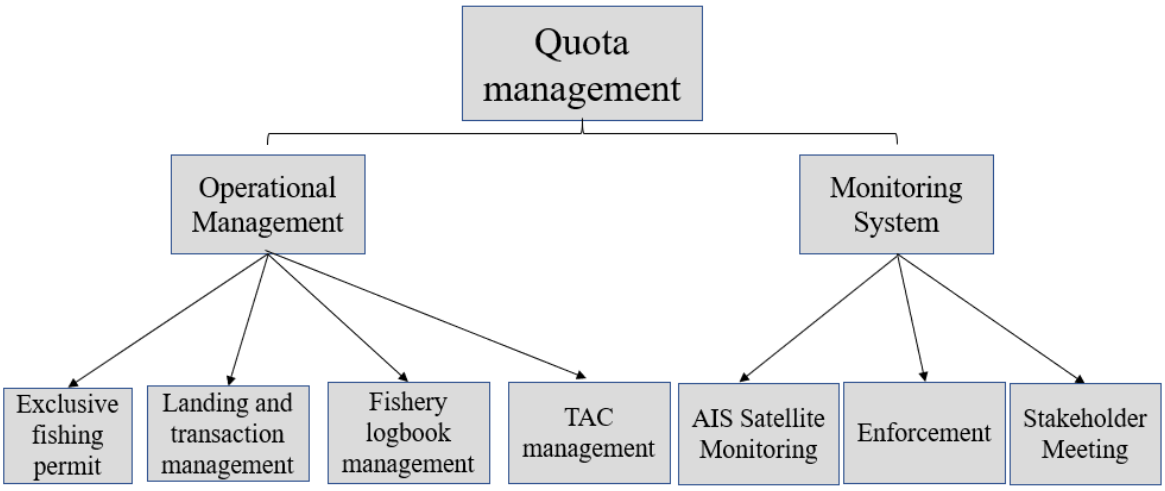

Figure 5: Conceptual map of PCPP Management Structure

The core essences of China's PCPP management system introduces four components into a designated provincial-managed waters based on existing national fisheries management. They are summarized and elaborated as follows.

- Output control in the form of Total Allowable Catch under the precautionary principle
- Olympian free-lancing fishing
- Develop exclusive fishing right mode for a pilot program for fishing entities pilot fisherfolks
- Improve fisheries data collection via fisheries logbook and AIS monitoring
- Establish a reward system for compliant PCPP fishing entities

First, the harvest tactic of China's PCPP has implemented a non-distributable catch quota system. The total quota for *Portunus* crab catches in PCPP jurisdiction is determined by Total Allowable Catch (TAC) as the catch limits. Given limited fisheries data are available for PCPP's quota setting, TAC has a high dependence on historical and initial-year catch data. It is mandatory to record *Portunus* crab actual catch from fishing operations within the pilot waters record in the paper-based fisheries logbook on a daily basis. PCPP fishery managers collect these catch data from pilot vessels as the basis of the usage of allowable catch quota. During the fishing season, landings are accumulated daily. The precautionary principle requires the fishery closure when landings reach to 95% TAC considering implementation uncertainty.

Second, the current *Portunus* crab pilot program does not allocate catch quota into at an individual level or allow transfer. The TAC is established as the management target to limit *Portunus* crab catch for all eligible pot vessels operating within PCPP's pilot waters. In PCPP's initial year, the whole program follows a "Olympic-style fishing", which is also termed as derby fisheries in NOAA fisheries glossary (Huang & Tang, 2010; NOAA, Accessed at May 7, 2019). The precautionary principle requires the fisheries closure when total catch reaches to 95% Total Allowable Catch.

Third, one of the management objectives in PCPP is to establish exclusive fishing permit for eligible pilot pot vessels with their privilege fishing rights within the pilot waters. It is not specified in the PCPP management plan that there exist the criteria that pertain to entry. Interview results identify that targeted fish stock, historical exploitation of targeted fish resource, the accessibilities of fishing communities to targeted fish resource, available management capacity and a controllable number of fishing fleets in one administrative jurisdiction are important factors with respect to the selection of PCPP fishing eligibility. The study identifies that most current pilot owners Most pot fishing owners in PCPP are identified as the fishing community residents in Xi' Qian, where has smaller number of *Portunus* crab fishing entities and is adjacent to South Fujian *Portunus* crab fishing ground. They are identified with special PCPP fishing permits and identification marks and obligated to report their catch data, vessel locations, and other types of information.

Fourth, China explores fisheries logbook into its existing fisheries data collection via pilot programs like PCPP. To optimize this collection with cost-effective management approaches, fixed landing and transaction system is introduced in the designated ports and certain qualified at-sea vessels. While an observer program has not yet been implemented in PCPP, port-based inspections on each catch and transaction are developed to comparatively test the accuracy of fisheries logbook data. The daily-recorded fisheries logbook data are mandatory to be submitted to PCPP fisheries authorities on a monthly basis and serve as the quota usage evidence. Automatic Identification Satellite (AIS) system is also introduced in PCPP to collect real-time vessel position data.

Fifth, PCPP develops a reward mechanism to increase the compliance of fishing entities with respect to PCPP regulations. There are two types of subsidies regarding eligible pot vessels in PCPP. One type is used for eligible pot vessels that comply with regulations in PCPP. Individual

pot vessel owners are is designated to receive with subsidies valued at approximately RMB 2,000 (USD 730) as the recognition of their participation in PCPP as well as a means of encouraging their compliance to PCPP regulations (i.e., timely submission of fisheries data logbooks). Another type is the fuel subsidy that applies to fishing vessels on a national scale. Given China's national fisheries policy is moving toward the scenario of controlling its domestic fishing pressure, the fuel subsidy in Fujian Province is gradually being adjusted to encourage the transformation of non-fishing employment, the elimination of outdated fishing vessel, and the reduction of subsidizing fishing unit efforts (i.e., 2500 RMB/kilowatt in 2015-2016 to 1000 RMB/kilowatt in 2018), etc. However, the punishment mechanism in PCPP is not specified in the management plan, which implies an unchanged fisheries enforcement in the PCPP jurisdiction in comparison to the pre-PCPP stage.

In addition, PCPP management plan calls for multiple enforcement tour during PCPP's implementation season to address non-compliances, conflicts, and IUU fishing with penalty regulations. In case of conflict and other unsolved issues, the provincial government will assemble fisheries managers, provincial fisheries institution researchers, and fisherfolk representatives into a negotiation if needed.

2.3.4 *Challenges Under the PCPP Management Plan*

For integrated of the interview results and analysis of the natural, human, and management sub-systems, this thesis identifies six major challenges in the current practices of *Portunus* crab pilot program. First, there has not yet a universal understanding among stakeholders with regard to the definition of a quota-based fishery management system. While all stakeholders recognize the importance of ecological sustainability in conserving marine fishery resources, sustainability at social, community, and institutional aspects commonly receive much less attentions in the upper-

level management structure [A2, M1, M2]. Although the philosophy of quota-based fishery management has been reflected in Fisheries Law of People's Republic of China in 2000, it has not been implemented in China's coastal fisheries due to a series of practical issues, including limited data availability, insufficient capacity support, and of pervasive non-selective fishing practices (Cao et al., 2017). Without previous examples and demonstrated experience in China's domestic marine fisheries, quota-based management is an unfamiliar territory to Fujian's fishery managers [M1, M2]. All interviewed fishing entities indicates a limited understanding of the definition of quota-based fishery management system. F3 and F4 claim that they basically follow the administrative regulations in *Portunus* crab pilot program with a reluctant attitude toward new things. N1 indicates *Portunus* crab industry takes a neutral standing to see the outcomes of this pilot management program. For relevant private sectors in *Portunus* crab fisheries, the increasing market demand makes them concerned about the influence of PCPP on their *Portunus* crab supply (I1, I2). Compared with "traditional" *Portunus* crab fishery in South Fujian waters, there has not yet adequate evidence to support PCPP's significant impact on *Portunus* crab supply chain. Considering a limited quantity of pot vessels and limited jurisdiction delimitation At PCPP's initial stage, the thesis does not recognize market impacts as one of the challenges discussed in this section. However, improving China's existing marine fisheries management in the direction of sustainability generally reaches consensus among the different groups of stakeholders. Despite the concerns that may exist, quota-based fishery management is considered as an essential first step in China's marine fishery reform toward sustainability [G1, G2, M1, M2, A1, A2, A3, N1, N3, N4]. Second, PCPP's management performance is compromised given the incompatibility problems between China's existing legislative framework and PCPP management plan. The most significant problem is the incompatible issue between China's fisheries license system and PCPP management

plan. The fisheries license system is one of China's national fisheries management systems for the plan of fisheries operation and production (Huang & He, 2019). Fishing licenses entitle licensed fishing entities with the fishing rights in conformity with the type of fishing operation, geographical scope, time limit, amount of fishing gear and the fishing quota (Congress, 2013). In South Fujian's provincial waters, licensed fishing entities registered in one municipal department of fisheries are lawfully permitted to fish not only in its own municipal waters but also in other Fujian municipal waters. It results in the licensed fishing practices of non-PCPP fishing vessels in PCPP jurisdiction without being subject to PCPP regulations. Given few legal clauses are available to explain the rights and liabilities for PCPP fishing entities, PCPP's exclusive fishing right is compromised by intermunicipal fishing practices from non-PCPP fishing entities. It becomes a challenge to PCPP fisheries enforcement to establish an exclusive fishing jurisdiction and an infringement of fishing entities with eligible rights in PCPP jurisdiction [M1, M2, F1, F3]. As PCPP management plan is a subnational fisheries regulation with inferior legal authority than national fisheries regulations, its incompatibility issues with China's existing fisheries management framework require legislative revisions to address the deficiency of China's fisheries legislative system.

Third, there exist misaligned stakeholder interests that challenge the scientific principles of implementing catch limits in PCPP. As the PCPP implements catch limits in the form of total allowable catch, quota setting has a significant influence on the performance of PCPP management system. However, inconsistency of interests among stakeholders results in different preferences with respect to quota quantity. For stakeholders in government, fisheries manager, and academia groups, their interests in PCPP align with management objectives, which are crab fishery sustainability and exploring feasible management strategies. For stakeholders in fisherfolk and

industry groups, their interests in PCPP are closely associated with the livelihoods of individuals and businesses. The divergence of their interests challenges the scientific principles of PCPP's quota-based catch limits with respect to practical issues. One aspect is derby fishing situations due to the design of Olympic-style fishing. Given the non-distributable quota system, it is likely that fishers tend to maximize their individual benefits in the opening of fishing season, which could induce severe competition, unsafe fishing practices, and the reduction of economic profitability (Wilen, 1979; Homans & Wilen, 1997; Pfeiffer & Gratz, 2016). Another aspect is the incentive of fishers' compliance on PCPP regulations. As fisherfolk group tends to own a higher total catch quota, a gambling relationship is developed between fisheries data report and setting catch limits. In PCPP's initial implementation stage, the authenticity of fisherfolk's catch data largely influences the quota setting in the next year [A2]. To win a higher catch allowance, a logical approach for fisherfolks is to make a false report to fishery authorities (Pope, 1976; Tang & Tang, 2003). Theoretically, if reported catch data are falsely larger than real catch in the first year, fisherfolks may obtain a larger catch quota in the second year at the expense of the reduction of fishing season in this year. If reported catch data is a falsely lower, it may result in the extent of fishing season this year at the expense of lower catch quota in the second year.

Fourth, inadequate management capacity to support the current policy practices compromises the management performance in *Portunus* crab pilot program [M1, M2, A1, A3]. A recent review of Zhejiang *Portunus* crab pilot program indicates the lack of effective monitoring system and limited capacity of management personnel capacity makes the program unable to provide timely monitoring of a large number of fishing vessels in multiple fishing ports (Chen & Zhu, 2018). The problem exists as a national-level challenge across China's coastal fisheries (Tang & Tang, 2003). M1 claims that it is challenging to currently address at-sea transaction and IUU fishing with limited

monitoring and supervision capacity, limited human resource and incomplete technical and infrastructure base.

Fifth, multispecies issues in fisheries management are oversimplified in PCPP management considerations. The quota setting in PCPP intends to align with maximum sustainable yield (MSY) via representing all Portunus crab species into one single "fishery" management unit. It seems to be a temporal and cost-effective approach given their similar life characteristics, spatial distribution, market category, and the data type of China's fisheries statistics division of treating *Portunus* crab as single category. However, it fails to consider the complexity in mixed fisheries, including but not limited to the complexity of attaining MSY in multiple and interacting species regarding the effect of biological interactions in mixed fisheries (Pope, 1976), dynamics in the abundance of predator and prey species (Collie, Gislason, & Vinther, 2003), potential damages to ecosystem structure (Walters et al., 2005), ignorance of the food-web effects on non-target species in multiple trophic levels with respect to maximum harvest yield (Matsuda & Abrams, 2006), total MSY's adverse impacts of biological diversity on competitive community (Geček & Legović, 2012), trade-offs of a variety of management strategies that lead to different socio-ecological profitability (Voss, Quaas, Schmidt, & Hoffmann, 2014), and stability relationship between yield and fishing low-tropic level species (Smith et al., 2011). These issues should be taken into account in the future development of PCPP regarding their potential impacts on ecosystem, effects on other species, trade-offs between yield and other management considerations. The success of addressing this challenge expects a ecosystem-level understanding in the fisheries management plan. In this thesis, the systematic fisheries approach focuses on tutoring PCPP management objective toward a sustainable development in the multidimensional fishery. It includes considerations of maximum sustainable yield and proposes a larger picture (Rindorf et al., 2017).

Sixth, there exist institutional limitations with respect to stakeholders' unbalanced participation in PCPP initiative. PCPP's management design originates from China's hierarchical fisheries management structure. In this context, stakeholders in PCPP's decision-making processes primarily belong to government, fishery manager, and academia groups. It results in the underrepresented issue for other groups of stakeholders. There has yet a formal institutional pathway in PCPP management plan that provides the inclusion of stakeholders in industry and NGO groups. Instead, stakeholders in the industry and NGO groups seek for alternative pathways (i.e., FIP stakeholder conference; establishing Memorandum of Understanding with government) to express their interests. In terms of stakeholders in fisherfolk group, their appeals are informally reflected through their interactions with local fisheries managers and a representative pathway in PCPP's stakeholder assemblies.

2.4 REVIEW OF *PORTUNUS* CRAB FISHERIES WORLDWIDE

Considering the availability of existing research on Portunidae crab fisheries, the study identifies blue swimming crab (*Portunus pelagicus*) as the target species and reviews *Portunus* crab fisheries and their management in four jurisdictions worldwide. They are the Philippine, Indonesia, Taiwan Province (China), and Australia. The case studies aim to explore the following questions: 1) what are the existing and proposed management measures of *Portunus* crab fisheries in these jurisdictions? 2) what are *Portunus* crab stock status based on the available stock assessment research? and 3) what implications can China's PCPP take from the demonstrative examples of *Portunus* crab fisheries management?

2.4.1 *Philippine*

The Philippine National Fisheries and Aquatic Resource Management Council established a detailed Blue Swimming Crab Management Plan in 2012 (Department of Agriculture Bureau of Fisheries and Aquatic Resources, Accessed at May 28, 2019). Its national management plan covers fundamental fisheries management practices such as mesh size regulation, fishing capacity control, gear restriction, closed fishing season, and developing guidelines for discarding bycatch.

Nevertheless, the Philippine management plan proposes different regulatory dimensions in terms of basic biological parameter research, bycatch issues, and hatchery techniques for possible stock enhancement. It implies a policy-oriented objective by investing research efforts on science-based fisheries stock assessment and transforming the assessment outputs into management practices. Besides, the Philippine's fisheries management plan focuses on single *Portunus* crab species despite similar multispecies characteristics exist in its fisheries system.

The Philippine Blue Swimming Crab Management Plan is the national-level legal framework that provides the enactment of regulatory measures through Fisheries Administrative Orders and Joint Administrative Order (*Philippine Blue Swimming Crab Fisheries Improvement Project FINAL Pre-assessment report*, 2015). It puts forward the concept of implementing quota-based fisheries management via fishing license and gear quota allocation to individual fishing entity. However, there is no evidence regarding the implementation of this quota system.

Philippine's national management plan on blue swimming crab is well developed. But the stock assessments show the opposite results. A recent research paper in Eastern Visayas indicates that management jurisdiction is incomplete in relation to the whole fishery and that there is poor implementation of management regulations, like minimum size limits, which has jeopardized its effectiveness (De La Cruz, 2015). A stock assessment in the Western Visayan Sea supports the

perspective that recruitment overfishing is occurring with more than 50% percent of premature size individuals are caught by gillnets, crab pot and otter trawl (V.Mesa, Bayate, & Guanco, 2018). The failure of crab fisheries management indicates the importance of capacity support in fisheries enforcement and proposes a cost-effective management plan to fit the current management basis.

2.4.2 *Indonesia*

The Blue Swimming Crab fishery in Indonesia is commonly a small scale fishery using gillnets, traps and mini trawl nets in the coastal waters (Wiyono & Ihsan, 2018). Indonesia adopts an integration of bottom-up approach and top-down government policy regarding Blue Swimming Crab fisheries management, which assigns management responsibilities to local governments and administrative responsibilities to Provincial-level and District-level offices (Ghofar, Redjeki, Madduppa, Abbey, & Tasunar, 2017; Minister of Marine Affairs and Fisheries of the Republic of Indonesia, 2016). In 2015, a new fishery management plan was proposed, that calls for minimum size limit, prohibitions on landing egg-bearing females, the mandatory release of egg-bearing females and undersized blue swimming crabs alive, the ban on coastal trawls and seine nets, under a fishing permit system (Seafood Watch Consulting Researcher, 2018). Given limited monitoring and no explicit harvest strategy for this fishery now, the performance of the Indonesian Blue Swimming Crab fishery is in its starting stage.

A recent study reports on the Blue Swimming Crab fisheries research in one of the most fishing grounds in Pangkajene Kepulauan, South Sulawesi. Wiyono and Ihsan (2018) identified higher fishing efforts being employed compared to the fishing level at maximum sustainable yield (F_{MSY}). With the consideration of the seasonal variations of crab abundance, year-round fishing practices for livelihood needs, and the dynamic fishing behaviors of local fisherfolks in response to crab

abundance fluctuation, the management recommendations proposed include fishing effort control, effort dynamics approach and community-based co-management (Wiyono & Ihsan, 2018).

2.4.3 *Taiwan (China)*

Taiwan fisheries statistics in *Portunus* crab also lacks breakout of *Portunus* species. The basic unit of Taiwan China's fisheries category is family (e.g., Portunidae), which reflects the family-based *Portunus* crab management instead of single-species management.

Portunus crab fisheries in Taiwan exhibits a high degree of overlap with the management of *Portunus* crab species in relation to China's PCPP. Wu (2002) and Huang (2005) *Portunus sanguinolentus, Portunus pelagicus, Charybdis miles* and *Charybdis feriatus* are common exploitation Portunus species in Taiwan coastal waters and China's PCPP.

Taiwan Fisheries Agency has implemented three harvest regulations on Portunus crab since 2014 [68]. First, a minimum size (carapace width) limit is set to prevent undersized *Charybdis feriatus, Portunus sanguinolentus, Charybdis natator, Portunus pelagicus,* and *Ranina ranina* from being harvested. Second, a spawning closure from August 16 to December 15 is implemented on egg-bearing females. Third, *Portunus* crab bycatch cannot be retained or landed. *Portunus* crab bycatch from gillnet should be removed and placed in life-sustaining containers and be released alive within 12 hours.

2.4.4 *Australia*

Australia has implemented a Total Allowable Commercial Catch (TACC) policy for both pot fishers and marine scale-fish (MSF) fishers through quota allocation in the southern Blue swimming crab (*Portunus pelagicus*) fishery (Spencer Gulf and Gulf St Vincent fishing regions) since 1996[69]. Only a limited number of management tools were applied in in the fishery before

the introduction of this quota-based management policy, including minimum size limits, seasonal closure, equipment restriction, and a prohibition on harvesting ovigerous females.

However, one of the key differences between China's PCPP and Australia's TACC is the scope of fishery management. While *Portunus pelagicus* is a single-species fishery in Australian pot and marine scale-fish fisheries, this species is just one kind of *Portunus* crab among China's multispecies in South Fujian and Taiwan fishing ground. Given the need of management innovation and capacity limitation, China's PCPP does not include gillnet into the TAC management system despite its significant *Portunus* crab catch [F1,F2,F3,F4]. Instead, TACC in Australia scopes two fishing gears into management and successfully control the total commercial efforts. In TACC post-implementation years, fishing efforts down decreased and is maintained stable in a relatively lower level (Department of the Environment and Heritage, 2004). It also induced the conversion of fishing types has been observed from MSF marine scale-fish license to pot license.

Australia has developed a management strategy that integrates fishery-independent survey and catch and effort logbook data into fisheries assessment. The robustness of its TACC annual setting depends on its stock assessment comparing the current status of catch, relative exploitation rate, pre-recruit, and sex ratio in related to interim target reference and interim limit reference (Department of the Environment and Heritage, 2004). Australia's *Portunus* crab assessment method provides implications on its data collection and the scientific basis of TAC setting.

In the western Australia which does not have a TACC program, the minimum size limits and entry control in *Portunus pelagicus* fishery in Cockburn Sound are inadequate for achieving fisheries sustainability (Johnston, Harris, Caputi, & Thomson, 2011). From an ecological perspective, *Portunus pelagicus* has been susceptible to environmental variation through a strong correlation

between water temperature and recruitment success (de Lestang et al., 2012). The observed reduction in spawning stock and recruitment individuals in Cockburn Sound indicates that a recruitment failure, which is believed to attributed to adverse environmental conditions like colder water temperature in some years(de Lestang et al., 2012; Johnston et al., 2011; Lipcius & Stockhausen, 2002). From the fishery management perspective, the conversion from gillnet to hourglass traps has witnessed an increase in catch and effort during the entire fishing season from December to September (Johnston et al., 2011). Despite a closed spawning season in October and November, more spawning females are susceptible to trap fishing during the winter fishing season, which significantly influences the spawning potential and lowers the number of juvenile crabs as recruited into the fishery in the next season. To set an appropriate level of fishing, the *Portunus* crab fishery in western Australian uses a juvenile and residual index to adjust fishing season duration in order to maintain spawning stocks above the pre-determined reference level. Australia example suggests that protective regulations need to be implemented for spawning females during over-wintering period and environmental influences on *Portunus* crab recruitment need to be integrated into management design.

Chapter 3. A MULTIDIMENSIONAL PARTICIPATORY APPROACH TO ASSESSMENT SUSTAINABILITY ON PCPP

As mentioned in the first chapter, the PCPP has implemented quota-based management measures to advance sustainability at Fujian's *Portunus* crab fishery and provide implications to other domestic marine fisheries. An analysis of PCPP's management plan as an example of China's marine fisheries reform indicates that China's current paradigm shift in marine fisheries highlights fish resource conservation, management measure improvement, and monitoring and supervision

enhancement. However, achieving sustainability in an intrinsically complex natural resource system, including Fujian *Portunus* crab fishery, will need additional measures beyond China's present emphasis on ecological dimensions. The complexity of a fishery system concerns the specific variables in their interactions within the social-ecological system (SESs)(Ostrom, 2009). Given such complexity, a literature review regarding fishery system sustainability leads to an integrated multidisciplinary understanding that perceives fisheries as a system, which includes interrelated and interacting ecological, biophysical, socioeconomic, and culture components (Charles, 2001; T. J. Pitcher et al., 2013; T. Pitcher & Preikshot, 2001). The, social-economic components in China's marine fisheries management receive inadequate attention. To provide a way of systematically examining sustainability of China's marine fisheries, this thesis proposed proposes a multidimensional assessment framework to define and assess fisheries sustainability in the PCPP.

Based on the existing available qualitative and quantitative data and the stakeholder perceptions from the study's human subject research, this study identifies a multi-criteria analysis (MCA) methodology to synthesize all data into a multidimensional framework (Mendoza & Prabhu, 2003). MCA is recognized with its theoretical robustness and practical advantages of systematically structuring a mixed set of data types and enabling collaborative planning and, stakeholder involvement in the decision-making processes to analyze a complex and stochastic system like fisheries (Hernández Aguado, Segado Segado, & Pitcher, 2016). Therefore, MCA qualifies as an ideal technique in this study to assess *Portunus* crab fishery sustainability from a multifaceted and systematic perspective.

In this study, MCA is used to develop five dimensions and a set of sustainability indicators for China's PCPP based on the sustainability at fishery system proposed by Charles (2001) and a rapid

appraisal technique proposed and as modified by Pitcher et al. (2013) known as Rapfish (Charles, 2001; T. J. Pitcher et al., 2013; T. Pitcher & Preikshot, 2001). Instead of developing quantifiable indexes for sustainability measure, the study focuses on the development of a list of five dimensions, a set of sustainability indicators, and their operational definitions for the PCPP fishery system (Table 3). Considering that it is the PCPP's initial year of implementation at this stage, the present study lays the basis of further analysis including but not limited to ranking each indicator by its degrees of importance, analysis of indicator linkages, interactions, and connections, and quantifying expert judgement into a numeric scale (Adrianto, Matsuda, & Sakuma, 2005; Hernández Aguado et al., 2016).

Table 2: The framework includes five dimensions and indicators for China's PCPP system.

Dimensions	Indicators	Operational Definitions
Ecological	Exploitation status	Assessment of current exploitation efforts in the PCPP relation to total crab resource
	Species changes	Trend in species composition of catch
	Vulnerability	Understanding of vulnerability in the swimming crab multispecies fishery
	Catch size	Understanding if the average crab size is changed
	Catch before maturity	Understanding of crab percentage caught that are smaller/younger than the size or age at maturity
	Bycatch	Understanding of nontargeted landing biomass
	Migratory pattern	Understanding of the migratory characteristics of crabs in their life history
Technological	Fleet capacity in relation to resource	Assessment of capacity in the catching power of the fishery
	Trend in catching power	Assessment of the trend of altered gear and vessel with respect to catch power
	Fishing gear side effects	Understanding of fishing gear's side effects on the habitats and other species
Socioeconomic	Infrastructure status	Understanding of industry capacity in landing, processing, distribution, and marketing crabs
	Extent of local ecological knowledge	Degree of indigenous knowledge that contributes to sustainable fishing practices, ownership, management decisions and governance
	Equity in fishing benefits	Spatial and demographic equity in benefit distribution
	Marketing system	Understanding of the impact of the marketing system
	Commoditization	Understanding of fishery product as a global commodity
Ethical	Alternatives	Understanding of alternatives to the fishery as sources of support within the community
	Equity in entry to fishery	Consideration whether entry to the fishery is based on traditional and historical access
	Just governance	Consideration of the inclusion of fishers in management and governance
	IUU fishing	Understanding the degree of illegal and unreported fish catches in total fishing practices
Institutional	Policy support	Assessing policy recognition and capacity support from superior authorities
	Governance qualify	Assess PCPP overall quality of providing enabling conditions for quota-based management
	Subsidies	Understanding of presence of subsidies to increase compliance to PCPP

3.1 Ecological Sustainability Assessment

1) Exploitation Status

UN FAO categorizes global fisheries exploitation status into “underexploited”, “moderately exploited”, “fully exploited”, and “overexploited” given their operating yield level in relation to maximum sustainable yield (FAO, Accessed by June 14, 2019). The detailed PCPP’s exploitation status assessment is discussed in Chapter 4 despite a considerable level of uncertainty which should be considered given the limited data available availability.

Due to their shared habitats and similar market category, *Portunus* crabs have been classified as one category in China’s Fisheries Yearbook Statistics since 1986. Despite missing statistics in 1988 and 1989 as well as small, but questionable production volume in 1993 and 1994, the overall *Portunus* crab production shows a growing trend in Fujian Province (Figure 6).

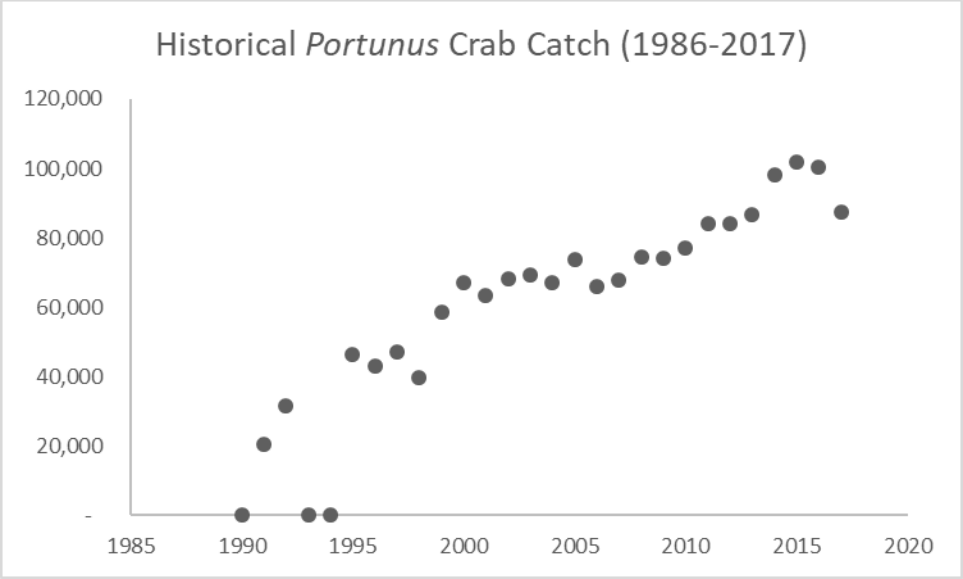

Figure 6: *Portunus* crab production in Fujian Province. Data extracted from China’s Fisheries Yearbook Statistics since 1986.

A recent species-by-species fisheries assessment for multiple *Portunus* crab species on the South Fujian and Taiwan fishing ground estimates the annual biomass of Portunus hannii (1.56*10^4 tons), *Portunus sanguinolentus* (4,064 tons), *Charybdis natator* (3,226 tons), *Charybdis japonica* (527 tons), *Charybdis feriatus* (261 tons) (Shen et al., 2018). Given PCPP’s 5.4% area ratio in

relative to the whole South Fujian and Taiwan fishing ground and assuming a uniformed crab distribution, the fisheries assessment results provides reference basis on setting TAC as the total catch limit in PCPP.

2) Species changes

There is little evidence of species change in China's official fisheries statistics since Portunus crab statistics. Shen and Liu identified 9 genes genuses and 26 Portunidae crab species in East China Sea, *including Portunus sanguinolentus, Portunus gracilimanus, Portunus hastatoides, Portunus hannii, Portunus argentatus, Scylla serrata, Charybdis cruciate, Charybdis miles, Charybdis gordonae, Charybdis variegate, Charybdis callianassa, Thalamita crenata, Libystes edwardsii, and Lissocarcinus polybioides* (Jiarui & Ruiyu, 1963). A recent fishery-independent survey in Central and South Fujian waters identified 6 genuses and 28 species *Portunus* crab species (Shen et al., 2014). All *Portunus* crab species and some of the Charybdis crab species in the Portunidae crab family are commonalities common to in two surveys, which reflects a generally similar crab species composition during the historical exploitation course. However, crab abundance may exist exhibit time-series variance given high-level pressure fishing practices and no specific conservation regulations. Traditional large and medium-size *Portunus* crab resource, like *Portunus sanguinolentus*, demonstrated which constitute a relatively low proportions in total survey catch, which are commonly believed to decline result from size-oriented fishing selectivity [32,34,79]. Small-scale swimming crabs, like *Portunus hannii,* has been dominant in the total catch in South Fujian and Taiwan area since the 1990s (Zhang, 1997).

3) Vulnerability

Fish species vulnerability is primarily based on life-history traits using FishBase criteria (Strona, 2014). They are used to measure the robustness of a specific fish species in resistance to fishing

pressure and external environmental processes. In the FishBase framework, life history traits involve body length, growth rate, life span, age at maturity, trophic level, and geographic range (Strona, 2014). Generally, large fish with low growth rate, long life span and late reproduction are the most vulnerable.

Brachyuran crustaceans, including *Portunus* crab species, indicates a higher resilience in response to external environmental impacts compared with other species (Kroeker et al., 2013). The common biological characteristics of *Portunus* crab in South Fujian and Taiwan waters may be used to assess their vulnerability. Swimming crabs commonly have a short life span with rapid maturity rate (Dai, Meng, Song, Huang, & Wu, 1977; Taylor, 2018; H. Wang, Wu, Wang, & Wang, 2001; J. Wang & Liu, 1996). They have high fecundity and multiple spawning cycles during the season (Wang et al., 2001). While China's current fishing intensity reduces the number of large and medium-size crabs, *Portunus* crab are in general not considered to be very susceptible to fishing pressure.

4) Catch Size

Historical fishing practices in South Fujian and Taiwan waters followed a "fishing down the food web" pattern, which led to the rising of crab abundance and the declining of fish population (Zhang, 1997). Traditional harvested *Portunus* crabs shift from large and medium species (i.e. *Portunus pelagicus*, *Portunus sanguinolentus*, *Pelagicus trituberculus*) to smaller-size species (Zhang, 2004). Shen (2014) illustrated that most crab species in central and southern part of Fujian waters were medium to small species (Shen et al., 2014). Overall, existing available research in PCPP indicates a decreasing trend in crab catch size in the long-term.

5) Catch before maturity

Since 2014, Ministry of Agriculture has implemented a minimum mesh limit (110 mm) on a national scale for gillnet, which is one of the main fishing gears for *Portunus* crab in South Fujian and Taiwan waters in the East China Sea. However, no mesh regulation on crab pots has been placed set given the almost exclusively pot fishing in PCPP. The pot is a standardized fishing gear with relatively higher selectivity to harvest crabs in comparison to trawl (S. Wang et al., 2017).

Variations exist in *Portunus* crab size due to environmental conditions and morphological difference among species. From one perspective, a smaller size at maturity can result from a slower growth rate under adverse environmental conditions, including low water temperatures and abnormal salinity [86,87]. From another perspective, sizes in *Portunus* crab varies from species to species. There are few data to assess the maturity-length relationship in multiple *Portunus* crab species. But according to Fujian Fisheries Research Institute's fishery-independent data and the dominant carapace width in the sampled identify, *Portunus sanguinolentus* and *Portunus pelagicus* to be subject to fishing throughout the season. The fish vulnerability and selectivity analysis are discussed in Chapter 4.

6) By-catch

Bycatch is defined as all fisheries-related mortality or injury other than the retained catch [85]. There is a relatively limited literature to document bycatch species composition in China's *Portunus* crab pot fisheries. Wang (2010) identified 72 species by of bycatch sampling catch from pot vessels in South Fujian and Taiwan fishing ground, including 40 finfish species, 23 crab species, 3 squillas, 3 cephalopod, 2 snail species, and 1 shrimp species. A recent fishery survey has identified 84 fish species, 12 crab species,7 shrimp species, 2 mantis shrimps, and 4 cephalopods through sample collection from bottom trawl and pot vessels. Except for *Calappa philargius*, the rest of crab species are all Portunidae crab family, including *Portunus hannii*

(mixed with *Charybdis miles, Charybdis sagamiensis), Portunus sanguinolentus (mixed with Portunus pelagicus, Portunus trituberculatus, Charybdis feriatus*), *Charybdis nataor (mixed with Charybdis amboinensis, Charybdis helleri, Charybdis acuta*). Crustacean species are both the dominant species in both surveys. A previous assessment in 2013 indicates "Best Choice/Green" rank of China's pot fishing bycatch, which indicates the fisheries are well managed and caught in ways that cause little harm to habitats or other wildlife (Taylor, 2018). It corresponds to medium inherent vulnerability of swimming crab, moderate level of crab population status, and low fishing mortality (Ye, Zhang, & Ye, 2004).

7) Migratory pattern

Crab abundance has noticeable temporal and spatial variances in Fujian coastal waters (Liu et al., 2011; Shen et al., 2014; Ye et al., 2004). A trawl investigation from 1994 to 1996 indicated high indices of abundance throughout the whole coastal waters from August to December and low indices of abundance in the fishing ground from December to June in the next year (Ye et al., 2004). Similar spatial-temporal pattern has been observed in 2006-2007 trawl survey and believed to be closely correlated to coastal water temperature (Liu et al., 2011). Wang et al. proposed over-wintering migration and spawning migratory in different seasons based on different *Portunus* crabs (Wang et al., 2001). The fisherfolk interview indicated their peak autumn-winter fishing practices in accordance to high abundance of crab during the period [F3, F4]. However, there exists limited available data demonstrating the exact spawning and overwintering geographic range in Fujian's coastal waters (Shen et al., 2018). Given that *Portunus* crabs are common in samples in the coastal waters while few crabs identified in the offshore waters, it is believed that *Portunus* crab migrates only as short coastal distance.

PCPP jurisdiction lies in the South Fujian's coastal water. There is significant amount of crab production within PCPP jurisdiction but pot vessels start their operation within PCPP jurisdiction in October [F1, F3, F4], which corresponds to the peak abundance in the coastal waters in autumn. PCPP jurisdiction lies in the South Fujian's coastal water. There is significant amount of crab production within PCPP jurisdiction but pot vessels start their operation within PCPP jurisdiction in October [F1, F3, F4], which. It corresponds to the peak abundance along in the coastal waters migratory pattern in autumn.

3.2 TECHNOLOGY SUSTAINABILITY ASSESSMENT

The estimation of *Portunus* crab historical total catch in PCPP is discussed based on area ratio and China's official fisheries statistics in Chapter 4. Based on *Portunus* crab biological parameters and PCPP fisheries data, a Total Allowable Catch (TAC) value is estimated for total *Portunus* crab catch.

According to Fujian's fisheries statistics in 2010, there are 209 pot vessels in Longhai, with 3,762 tons annual catch in total and 16,050.1kW total horsepower (Yutong, 2011). Assume unchanged conditions in individual pot vessel since 2010, it can be estimated that the 106 pot vessels in PCPP can produce 1,908 tons total catch during one year with 8,140 kW total horsepower.

2) Trend in catching power

There is are no historical catching power statistics, given it is PCPP's initial year. With better understanding of *Portunus* crab fisheries and data collection in the future, there could be adjustment on the number of allowable fishing entities. In addition, a " double control" management is implemented as a means of implementing input control in China's marine fisheries. It aims to put strict control on national fishing pressure by reducing the number and horsepower of fishing vessels (S. Huang & Tang, 2010). Fujian adopts this management means and develops

management targets for fishing effort reduction before 2020 (Ocean and Fisheries Bureau of Fujian, 2017). This policy context perceives a downtrend in catching power given current fisheries administration.

3) Fishing gear side effect

Pots are believed to be environmental-friendly gear with advantage of using less labor and to sort catch and saving on consumption of fuel (Lin & Jinfu, 1997). There is no documentary evidence of fishing operation using pot and the potential of damaging bottom habitat(Taylor, 2018). Compared to bottom trawl, crab pot has relatively higher fishing selectivity regarding crab harvesting (Wang et al., 2017). A variety of crab species and finfish species are identified in pot catch (see by-catch section) but crab accounts for the majority. FishSource ranks China's pot fishing practices in the "BestChoice/Green" category with respect to few impact on other retained and bycatch stocks (Wang et al., 2017).

3.3 SOCIOECONOMIC SUSTAINABILITY ASSESSMENT

1) Infrastructure status

PCPP pilot waters are administratively managed under Longhai, the county-level municipal government in Zhangzhou, South Fujian area. It is one of the core regions in China for crabmeat export trade, accounting for about 39% of total crabmeat products exported from China in 2014(S. Wang et al., 2017). The South Fujian and Taiwan fishing ground is the traditional fishing area in Fujian Province. A fisheries supply chain survey in 2014 indicated that there were 23 documented companies in total in the Zhangzhou region regarding crab production exports to the U.S. Most of the crabmeat processing and export facilities are in Dongshan County, including 11 processing factories engaging in crab processing and export business, with more than 20,000 employees (Wang et al., 2017). According to 2018 China's fisheries statistics, there are 22 fishing ports in

Fujian Province, many of them lie in South Fujian area with geographic advantage of proximity to fishing grounds. Crab industries purchase their raw material from landings in these fishing ports. Overall, the study identifies a well-developed fisheries infrastructure system regarding landing, processing, distribution, and marketing regarding Fujian crab production.

2) Extent of local ecological knowledge (LEK)

Local ecological knowledge (LEK) is understood as knowledge, practices, and beliefs regarding ecological relationships that are gained through extensive personal observation of and interaction with local ecosystem., and shared among local resource users (Charnley, Fischer, & Jones, 2007). The extent of LEK shapes resource use practices regarding the influence of local ecosystem biodiversity, environmental conditions, and resilience of their socio-ecological system (Joa, Georg, & Primmer, 2018). Regarding LEK in fishing resource use in South Fujian, traditional and local ecological knowledge has been well developed based on experience-based knowledge, ecological knowledge, and environmental knowledge. The majority of knowledge sources of interviewed fisherfolks is claimed to be inherent knowledge from the seniors and years of fishing practices [F1,F3,F4]. An incredible level of knowledge regarding understanding of crab abundance seasonal variation pattern is observed with the integration of unique biophysical environment in South Fujian and Taiwan Ecological subsystem [I1, F1]. For example, fisherfolks often conduct fishing practices before and after the typhoon to obtain a higher amount of catch; baits are effectively used in crab pots to maximize their catch; etc. Regarding environmental impacts, not just the adverse impacts of bottom trawling are identified, there exist concerns for the impacts of fish habitats from coastal fisheries infrastructure construction [I1, F1].

3) Change in fishing benefits

Eligible fisherfolks in PCPP, they are designated with exclusive fishing rights within PCPP jurisdiction and receive other forms of benefits (i.e., PCPP subsidy), which changes the previous fishing benefits among licensed fisherfolks in Fujian Province. The "trade-offs" for eligible PCPP fisherfolks include the compliance of introduced regulations, engaging in fishery data collection, and being managed under a catch limit system.

4) Equity of fishing benefits

Equity may not be the priority issue in PCPP management plan given its administrative purpose of exploring quota-based fisheries management practice. However, equity issue exists considering the incompatibility between PCPP management plan and fisheries licensing system described above. The study has limited information regarding the selection process of determining the eligibility of PCPP fisherfolks. To implement exclusive fishing right as one of the PCPP design goals, fishing rights for other non-eligible fisherfolks in South Fujian and Taiwan fishing waters may not be guaranteed within PCPP waters for the short-term period.

On a broader scale, PCPP is a designated area and pilot management plan as a means of approaching China's marine fisheries reform. Experience and better fisheries management system is expected to generate interest in fishery reform for other coastal fisheries. The cost of temporarily inequity and legislative incompatibility is the means used to provide greater fishing benefits based on fish resource sustainability.

5) Marketing system

According to Qing's (2017) value chain survey, fishing vessel owners in Zhangzhou are generally independent and self-employed "business operation individuals" regarding landing marketing (Qing, 2017). Individually owned and operated vessels and sales of fish catches indicates there is no formal fisheries association that plays the role of fisheries management for vessels or catches.

Local seafood market and processing enterprises are two destination for crab catch (S. Wang et al., 2017). The survey also identifies two pathways of crab processing, including 1) catch flows into local market via wholesalers, and 2) catch flows into processing enterprises via direct purchasing or middleman centralized purchasing (Qing, 2017). Currently, there has been no sign regarding PCPP impacts on crab raw material supply in local fisheries industry [N1,3]. This outcome is reasonable given PCPP's small area compared with the total area of Portunus crab fishing in South Fujian and Taiwan fishing ground and relatively limited crab production within PCPP waters.

6) Commoditization

As noted above *Portunus* crab has been commoditized into domestic and international export products. It has witnessed an increasing demand for crabmeat in U.S. seafood market based on U.S. Customs Statistics (Figure 7). This crabmeat trade between the U.S. and China, especially raw materials deriving from *Portunus hannii* and *Portunus sanguinolentus*, is considered to be exclusive to the South Fujian and Taiwan fishing area (S. Wang et al., 2017). The increasing demand from international seafood market indirectly boosts the development of fisheries industry in South Fujian area, as well as the intense fishing practices since the 1990 s(Zhang, 1997).

Regarding sustainability at *Portunus* crab population in PCPP, this study identifies an increasing trend in *Portunus* crab commoditization, which may be unfavorable to their sustainability without additional fisheries management measures.

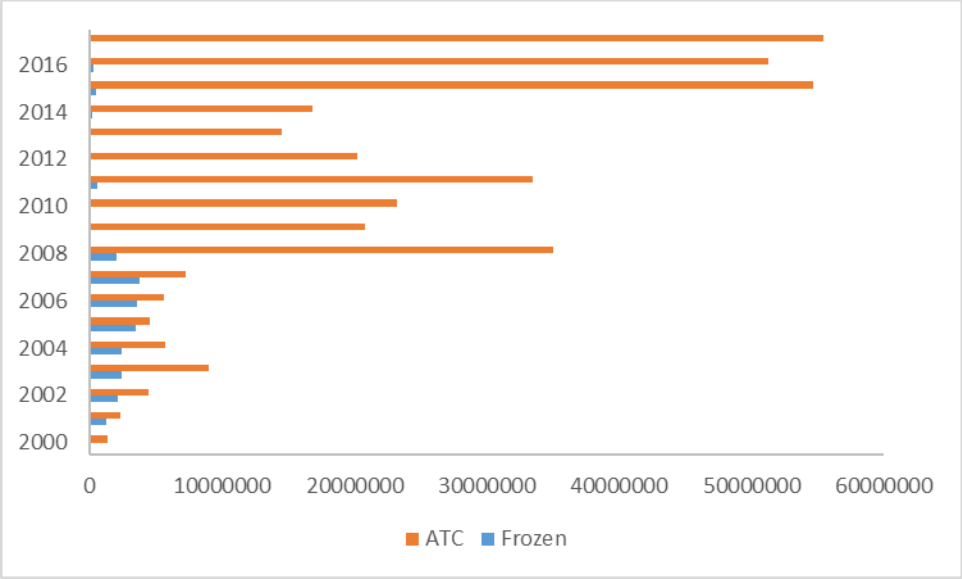

Figure 7: Historical Statistics of China's Portunidae Product Export to U.S. Market (National Marine Fisheries Service, 2019)

The figure takes historical statistics of China's *Portunidae* product export to U.S. Market. ATC Air Tight Container and Frozen refer to two different product type: Air Tight Container and frozen. This crabmeat trade between the U.S. and China, especially raw materials deriving *from Portunus hannii and Portunus sanguinolentus*, is exclusive to the South Fujian and Taiwan fishing area (S. Wang et al., 2017). The increasing demand from international seafood market indirectly boosts the development of fisheries industry in South Fujian area, as well as the intense fishing practices since the 1990s(Zhang, 1997).

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3.4 Ethical Sustainability Assessment

1) Alternatives

The study does not analyse analyze alternative livelihoods of fisherfolks within PCPP because of its recent implementation and the lack of prior data collection. However, fisherfolks population demographics are characterized as middle-age residents in the fishing community with relatively low educational background[F1,F2,F3,F4]. Two fisherfolks claimed they had to depend on loans and debits to maintain their livelihood during non-fishing season and pay their loan back during the fishing season [F3,F4]. Thus, the study perceives a limited alternative option regarding PCPP fisherfolks livelihood.

2) Just governance

PCPP fisheries management aligns with China's top-down management structure. The PCPP governance process flows from the development of the PCPP management plan by the Ministry of Agriculture and the Provincial Fisheries Authority to the concrete implementation via local fisheries administration and legal-operation departments at the municipal level. The inclusion of fisherfolks is institutionally supported through a stakeholder conference if issues occur during PCPP implementation. This study also identifies a benign relationship between local fisheries departments and fisherfolks on the basis of long-term administrative interaction [F1,F2,M1,M2]. Given the importance of fisherfolk's compliance of PCPP regulations, fisherfolks' perceptions are respected and may be informally inclusive via employees in the local fisheries departments. However, it more time and education is required to develop a better knowledge basis among fisherfolks regarding their understanding of PCPP management.

3) IUU fishing

Illegal, unregulated, and unreported fish in PCPP commonly refers to unauthorized fishing practices without compliance to China's existing fisheries legislative and administrative

regulations. On this basis, PCPP has introduced additional regulations to implement TAC-based fisheries management within its limited area of application.

However, the exclusive fishing within PCPP pilot waters is lack of solid legislative instrument. It is defined in PCPP management plan that fleets with special fishing licenses, PCPP identifiers have rights to fish under the obligations of PCPP regulations. Fishing practices from extraneous fishing vessels in PCPP jurisdiction, including licensed fishing vessels in other counties and illegal fishing vessels without fishing permits, identification documents, and registry, are considered as IUU fishing in this section. it is challenging to control the entry of non-eligible vessels without applicable laws and limited management capacity [M1]. It became a relatively contradictory to legislatively define IUU fishing considering their legal fishing status and non-affiliated PCPP management system.

3.5 INSTITUTIONAL SUSTAINABILITY ASSESSMENT

1) Policy support

Since the declaration of China's Ecological Civilization is highlighted in 17th the National Congress, State Council has recognized the importance of sustainable development of marine fisheries. In 2017, the Ministry of Agriculture published 13th National Fisheries 5-Year Development Plan, which guides the implementation of "total quantity management" for marine fisheries resource. The need of improving quantifiability, transparency, and accountability in the existing marine fisheries management leads to the development of quota-based fisheries management program, including PCPP. PCPP is one of China's first-tier quota-based fisheries management demonstration program which are designed as a means of exploring possible fisheries management innovations towards marine fisheries sustainability.

Approved and established by Ministry of Agriculture, the PCPP takes direction from the top-down fisheries management system with the leading and funding support from Fujian provincial fisheries authority. Therefore, the program is institutionally recognized by Ministry of Agriculture and supported by Fujian provincial fisheries authorities and other relevant fisheries agencies in multiple level of governments.

2) Governance quality

Enabling conditions for implementing quota-based fisheries management in PCPP are with the following aspects. Firstly, PCPP introduces a catch limit as the form of TAC to explore feasible quota-based management practices. The setting of a TAC value as the management target level is an important component that would make *Portunus* crab management into science-based management. However, the limited data available and lack of research at current stage of implementation compromise PCPP's performance in its initial year. Considering the intent of improving PCPP management design in the future work, implementing PCPP is initial step in a good start at developing an initial quota-based fisheries management plan and this is essential to set fishing capacity to match resource availability to increase social-ecological fisheries benefits.

Second, the incompatibility between PCPP management plan and fisheries license system indicates a relatively weak legislative basis for quota-based fisheries management. It is not only because of the transboundary fishing practices due to the gaps in fisheries laws and regulations, but also because of the limited capacity of transferring PCPP management into effective actions and monitoring. Considering the ongoing revision on China's fisheries laws and the implementation of the PCPP management plan, this enabling condition could be improved by a supportive legislation.

Third, the strength and consistency of policy support is also a necessary enabling condition for PCPP implementation. Since the Ecological Civilization was highlighted in China's policy agenda, it has been a long-term national strategic goal to improve natural resource management towards sustainability, including marine fisheries resource. China has published 13th 5-year plan to support the reform of marine fisheries. Following pilot programs in Zhejiang and Shandong Provinces, PCPP is China's third pilot program approved by Ministry of Agriculture and advanced by relevant interdepartmental fisheries authorities within the province. The recognition in policy brings significant capacity input into PCPP, including but not limited to subsidies, infrastructure & equipment, and science research, which provides start-up capital for supporting PCPP.

3) Subsidies

Stakeholder interviews indicate that there may be inadequate motivation for eligible fisherfolks in PCPP regarding compliance of introduced regulations [F1, F2, A1]. Despite PCPP's subsidy on eligible fisherfolks, the study has not identified alternative incentives to offset the cost to fisherfolks in the PCPP management system. From the perspective of fisherfolks, inadequate understanding of newly introduced TAC management system and limited motivations on voluntarily complying with PCPP regulations may be insufficient to increase their compliance given the limited management capacity.

Chapter 4. MANAGEMENT PRACTICES BASED ON FISH BIOLOGICAL MODELLING

As indicated in the first chapter, the second management objective in China's PCPP aims to explore available management practices that feasibly satisfy the biological characteristics of South Fujian and Taiwan *Portunus* crab. In PCPP's initial attempt, a quota-based fisheries

management tactics is introduced to implement a catch limit to the total *Portunus* crabs harvest within two designated waters (#282, 283 fishing grids). However, there have been rarely few reflections in the present PCPP fishery management procedures regarding what specific harvest strategies does PCPP implement on *Portunus* crab fisheries. A harvest strategy is the plan that is robust to uncertainties in fisheries stock and is implemented via a series of annual regulations, or harvest tactics(Hilborn & Walters, 1992). The annual catch quotas measure is one of the common harvest tactics in stock assessment. In addition, the setting of annual Total Allowable Catch (TAC) as well as the monitoring and enforcement tactics usually needs to be adjusted from year-to-year depending on the stability and predictability of the fishery(Hilborn & Walters, 1992). To provide implications on consequences of alternative PCPP's management practices, the study explores the catch-exploitation rate relationship under the fixed exploitation rate on *Portunus* crab stock using size-structured discrete-time model and evaluates alternative strategies using Data-limited Toolkits (Punt, Butterworth, de Moor, De Oliveira, & Haddon, 2016). Given limited available data in China's *Portunus* fisheries context and subtropical ecosystem with multiple *Portunus* crab species, existing data availability, PCPP *Portunus* survey data and available published literatures are primary sources for this study to identify the type of model and the target species. Based on a recent single-trawl survey from August 2017 to April 2018, *Portunus hannii* is the dominant *Portunus* species in local fishing grounds (Figure 1). A literature review also supports local ecological knowledge regarding the declining of traditional large and medium size *Portunus* crab species and *Portunus.hannii's* increasing production since the 1990s(Zhang, 2004). In addition, *Portunus pelagicus* as the traditional harvested species has been relatively studied regarding its biological characteristics and life parameters(Campbell, 2017; Gang et al., 2017). The study stimulates a theoretical *Portunus* crab based on existing

available stock assessment parameters for *Portunus pelagicus* and *Portunus hannii* as a representative "species" for *Portunus* crab "stock".

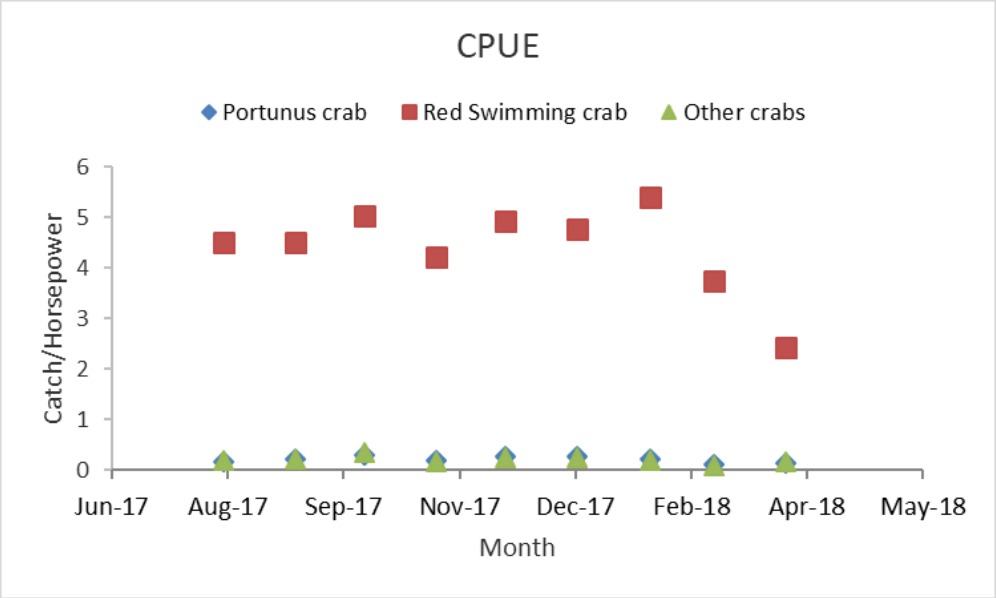

Figure 8: Catch per unit effort (CPUE) of Red Swimming Crab (*Portunus hannii*), other *Portunus* crabs, and other non-*Portunus* crabs based on a single-trawl survey

Based on existing available research data, this chapter has three objectives related to the development of PCPP quota-based fisheries management, including 1) the estimation of the assessment basis for this theoretical *Portunus* crab, including yield per recruit (YPR), spawning biomass per recruit (SBPR), and biological reference points, 2) consequences of this hypothetical *Portunus* crab species in response to four alterative harvest strategies – a) fixed exploitation rate, b) constant escapement, c) fixed proportional rate, and d) fixed quota management, and 3) other alternative operating model(s) for this theoretical *Portunus* crab species. The overarching purpose of this assessment offers a heuristic approach of estimating *Portunus* crab assessment basis and examining consequences of specific harvest strategies. The assessment outputs intend to offer implications for PCPP's current management and policy decisions under uncertain conditions.

4.1 PARAMETER DETERMINATION

Model 1: Size-structured discrete-time model

Table 3: Parameters for Model 1

Parameter	Value	Source
Surv	0.95	Model Setting
m50	65	Survey Data (FFRI)
m95	85	Survey Data (FFRI)
s50	70	Survey Data (FFRI)
s95	120	Survey Data (FFRI)
wc	0.000085	Survey Data (FFRI)
wb	3.063	Survey Data (FFRI)
Linf	130	Survey Data (FFRI)
K	0.103	Campbell, 2017
t0	-0.08	Campbell, 2017
LengthCV	0.08	Model Setting
steepness	0.5	Model Setting
rzero	1000	Model Setting

Parameter values for size-structured discrete time model are listed provided with data sources. Parameter values are modified with length unit as mm and monthly time-steps. Model Setting refers to default model values. Survey data (FFRI) refers to data provided by survey data in Fujian Fisheries Research Institute (FFRI). Surv is survival rate. m50 is 50% maturity. m95 is 95% maturity. s50 is 50% selectivity. s95 is 95% selectivity. wc and wb are constant coefficient in length-weight relationship. Linf, K, and t0 are parameters in von-Bertalanffy growth equation. K is the growth rate. Linf is L infinity, the asymptotic length when growth is zero. t0 is the initial fish size when age is 0. rzero is the estimate of recruitment in the unfished state.

Table 4: Parameters for Model 2

Parameter	Value	Source
Year	2000 to 2017	China Fisheries Statistics
Catch	Proportional estimated	FIP Investigation Report
Abundance	NA	
Duration t	18	China Fisheries Statistics
Average catch over time t	20,696	Average Estimation From “Catch”
Depletion over time t	NA	

M	0.129	Campbell, 2017
FMSY/M	0.62	Model 1 Output
BMSY/B0	0.0592	Model 1 Output
MSY	47,040	Model 1 Output
BMSY	26,459	Model 1 Output
Length at 50% maturity	65	Survey Data (FFRI)
Length at 95% maturity	85	Survey Data (FFRI)
Length at first capture	NA	
Length at full selection	NA	
Current stock depletion	NA	
Current stock abundance	NA	
VB K parameter	0.103	Campbell, 2017
VB Linf parameter	130	Survey Data (FFRI)
VB t0 parameter	NA	Campbell, 2017
Length-weight parameter a	0.000085	Survey Data (FFRI)
Length-weight parameter b	3.063	Survey Data (FFRI)
Steepness	0.5	Model Setting
Maximum age	3.5	FAO, 2013; Seafood Watch, 2018

Parameter values for Data Input File in Data-Limited Fisheries Toolkits are based on NRDC report (Newman et al. 2014). NA indicates data unavailability to the parameters. Four additional data sources in relation to Model 1 are China's Fisheries Statistics, FAO Species Fact, and Portunus Seafood Watch assessment report. Fishery Improvement Project investigation report (unpublished) that estimates historical *Portunus* crab catch proportional to gear selectivity. Model 1 Output indicates that parameter values are provided by the calculations in Model 1.

4.2 Estimations of *Portunus* crab Yield Per Recruit (YPR), Spawning Biomass Per Recruit (SBPR), and Biological Reference Points

Firstly, Function (1)(2) are used to examine *P.pelagicus* growth length and weight as follows. The exponential relationship between *Portunus* crab carapace width and its weight is:

$$W = wc * L^{wb} \quad \text{(1)}$$

In Function (1), W is the somatic weight (g), L is the carapace width (mm), wc is a constant coefficient, and wb is the power exponent.

Based on Von-Bertalanfy growth function, *Portunus* crab carapace width is calculated:

$L_t = L_\infty[1 - e^{-k(t-t_0}]$…….. (2)

In Function (2), $L_t$is the carapace width at age t, k is the growth coefficient, t0 is the theoretical value of the carapace width at age 0, L_∞ is asymptotic size.

All life parameters and Function (1)(2) are used to estimate length at age and weight at age.

Function (3) (4) are used to determine maturity at age and vulnerability at age.

$$m_t = \frac{1}{\frac{1+e^{-(L_t-m50)}}{\frac{m95-m50}{\ln(19)}}}$$…….. (3)

In Function (3), m_t is the maturity at age t. $L_t$is the carapace width at age t.

$$v_t = \frac{1}{\frac{1+e^{-(L_t-s50)}}{\frac{s95-s50}{\ln(19)}}}$$……. (4)

In Function (4), $v_t$is the vulnerability at age t. $L_t$is the carapace width at age t.

Regarding the estimation of recruitment, equilibrium formulae are used to calculate the *Portunus* crab Spawning Biomass per Recruit (SBPR) and Beverton-Holt spawning recruit curve (Lawson & Hilborn, 1985).

$N_1 = 1$

$N_a = N_{a-1}s(1 - v_{a-1}u) \;\; a > 1$

$SPR =$

$\sum_a N_a f_a$ ……

…….. (5)

In Function (5), N_a is numbers at age, s is survival from natural mortality, u is fishing mortality rate on fully selected individuals, v_a is relative vulnerability of age a individual. f_a is the fecundity at age.

$$R_\infty = \frac{E_\infty}{\alpha E_\infty + \beta}, \beta = \frac{z-0.2}{0.8 z R_0}, \alpha = \frac{B_0}{R_0}\frac{1-(z-0.2)}{0.8\ z}$$

…… (6)

In Function (6), R_0 is your estimate of recruitment in the unfished state and B_0 is the spawning stock biomass that results from that R_0 with no fishing mortality. z is the steepness.

Finally, estimations of crab population without fishing (virgin N) and crab population with fishing (N fished) are calculated based on Function (7)(8).

For virgin N, $N_1 = 1; N_{t+1} = N_t * surv$…….…….. (7)

For N fished, $N_1 = 1, N_{t+1} = N_t * surv * (1 - v_t * HR)$……..…… (8)

In Function (8), HR is the harvest rate.

Based on Function (1)-(8), the study estimates vulnerability, maturity, YPR, SBPR, long-term yield with different steepness, and reference points for *Portunus pelagicus*.

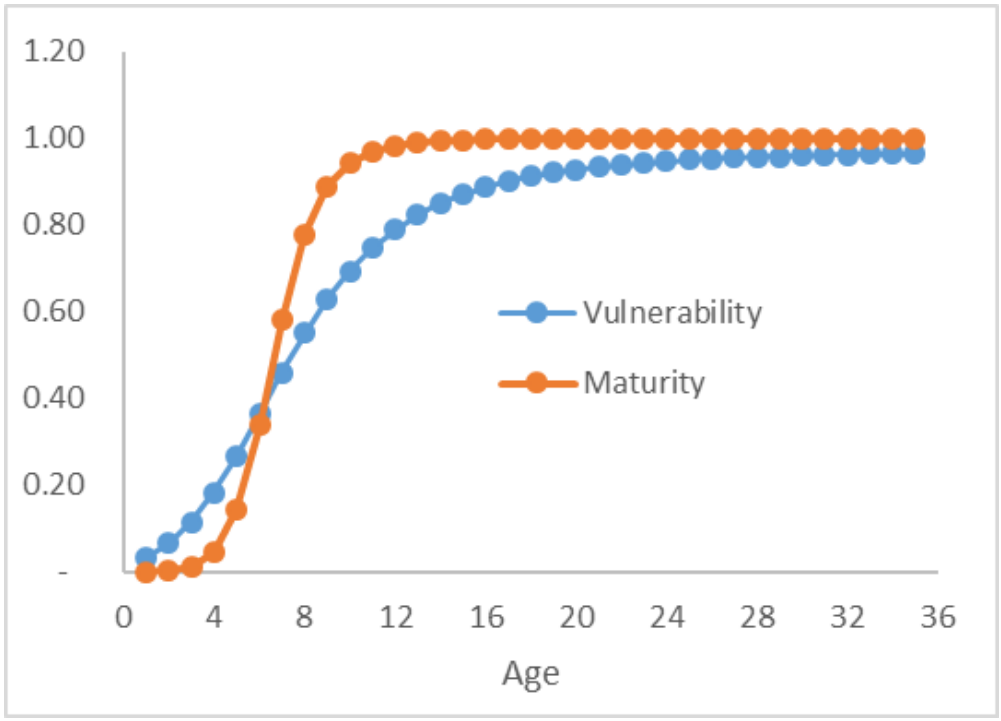

Figure 9: Vulnerability and Maturity Curve. Age is based on month.

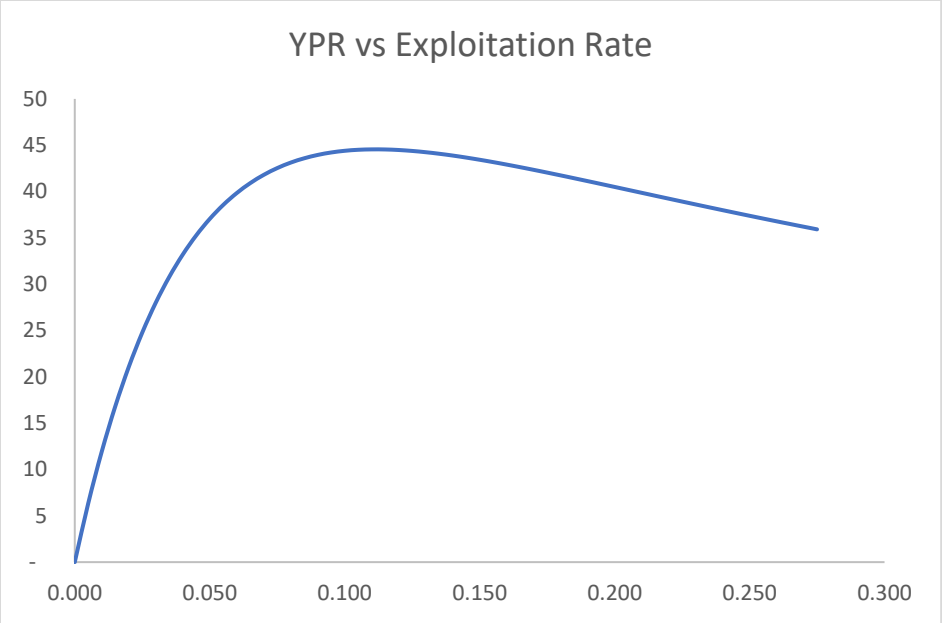

Figure 10: Yield per Recruit in relation to harvest rate

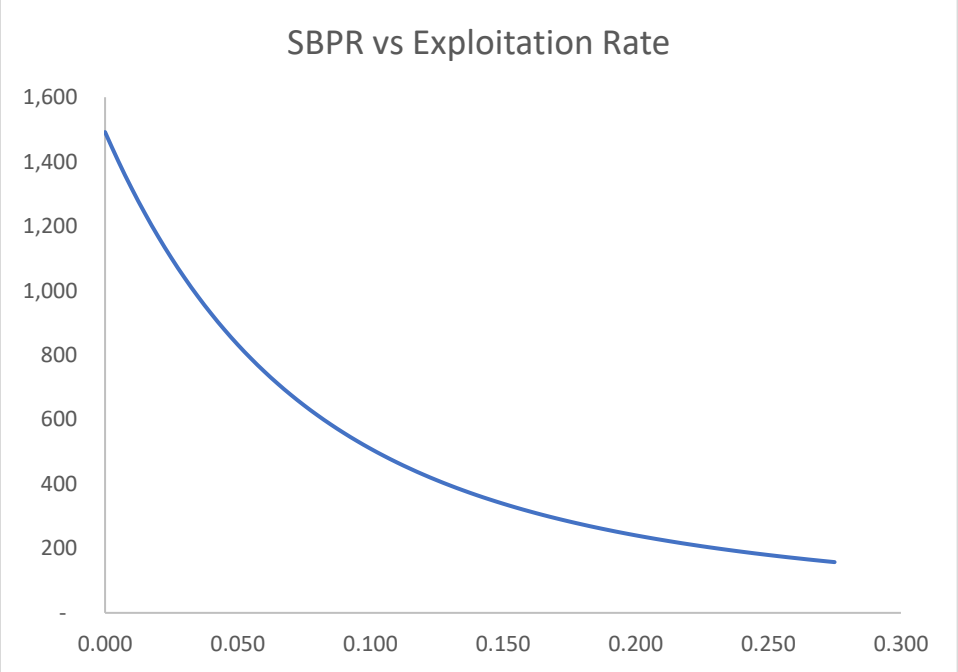

Figure 11: Spawning Biomass per Recruit in relation to harvest rate

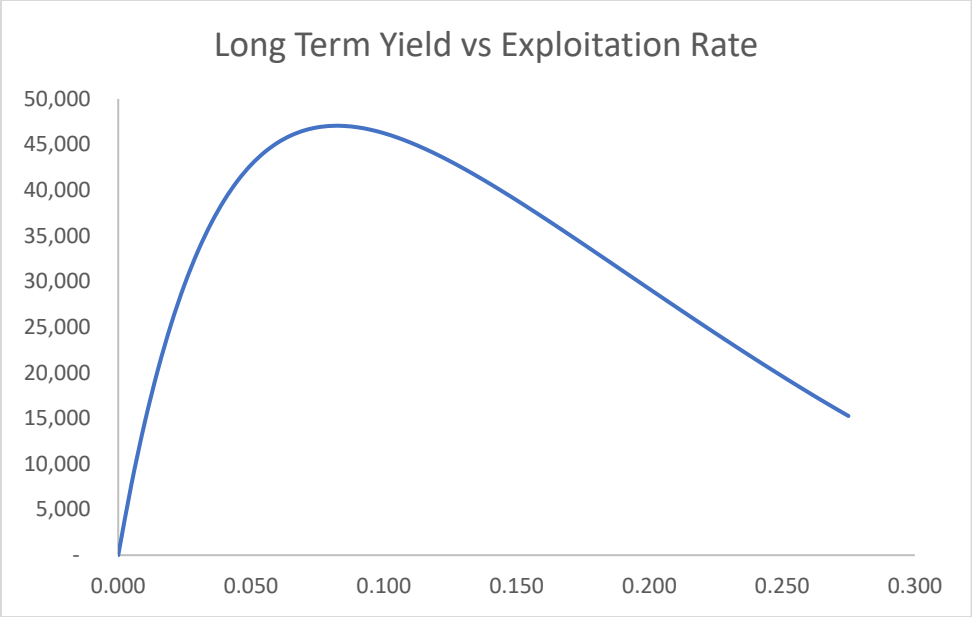

Figure 12: Long-term Yield in relation to harvest rate

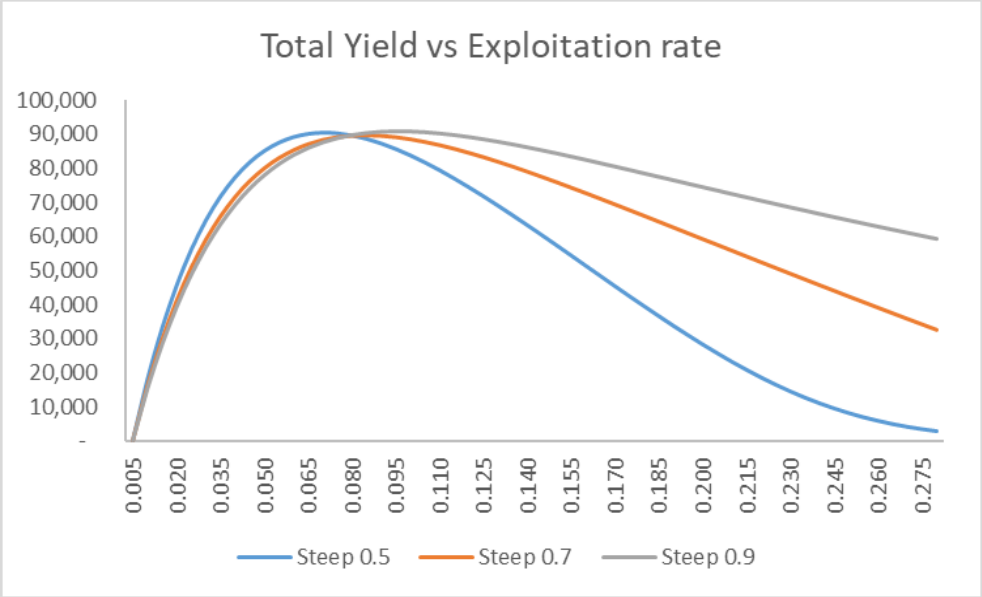

Figure 13: Total yield in relation to harvest rate under steepness 0.5, 0.7, and 0.9

Six types of reference points are estimated based on the figures to provide assessment basis for PCPP management implications.

Table 5: Fishing biological reference points with steepness 0.5, 0.7, and 0.9

Steep	F_{MSY}	$F_{SPR50\%}$	$F_{SPR40\%}$	$F_{SPR30\%}$	F_{max}	$F_{0.1}$

0.5	0.065	0.057	0.085	0.115	0.080	0.078
0.7	0.080	0.070	0.085	0.115		
0.9	0.100	0.070	0.085	0.115		

4.3 ALTERNATIVE HARVEST STRATEGIES TO THE PCPP – AN EXAMPLE OF FIXED HARVEST RATE

The quota-based management system in PCPP implements a total allowable catch (TAC) as *Portunus* crab management tactic. The underlying rationale of TAC tactic lies in the specific harvest strategy determined by the adjustment of catch taken from the stock on an annual basis and considerations including but not limited to the size of the stock, the economic or social conditions of the fishery, conditions of other stocks, and perhaps the state of uncertainty regarding biological knowledge of the stock (Hilborn and Walter, 1992). The manipulation of exploitation rate in fisheries stock assessment science leads to 4 paradigms in harvest strategies (Figure 14). The study examines 4 common harvest strategies to PCPP *Portunus* crab to analyze what consequences of *Portunus* crab in response to these harvest strategies and the evaluations of harvest tactics in PCPP that stems from alternative harvest strategies. Two alternative harvest strategies are a) fixed exploitation rate, b) constant escapement, c) fixed quota harvest, and 4) fixed proportion harvest. The thesis examines the fixed harvest rate management strategy and the consequences of yield in response to harvest level.

Fixed exploitation rate strategy aims to specifies the certain level of the effort on an annual basis in fisheries management. The study conducts the estimation of average yield based on a range of monthly harvest rate in the following steps.

$$\text{Vulnerability Biomass}_t = \sum(S_t * W_t * Vulnerability_t) \quad \text{.....(9)}$$

$S_t$is the number alive at beginning of the month at age t. $W_t$is the somatic weight at age t, which is calculated in Function (1). Vulnerability is calculated in Function (4).

$S_1 = virgin\_N * R_0$, virgin_N is the number of fish without fishing at age 1.

$Egg_t = \sum(S_t * W_t * m_t)$……(10)

$S_{t+1} = \frac{Egg_t}{\propto + \beta * Egg_t} * \exp(p * r)$…… (11)

p is the process random error and r is the recruitment variability with a fixed value at 0.6. α, β are the same parameters in Function (6).

Then, estimated population size at age t (EP_t) is calculated as

$EP_t = Vulnerability\ Biomass_t * Exp(observation\ error * o_{random})$……(12)

In Function (12), observation error is a fixed constant. O_{random} is the observation random variable.

The desired catch at age (DC_t) is calculated with Function (13) as follows.

$DC_t = Harvest\ rate * EP_t$……(13)

The actual catch at age (AC_t) is calculated with Function (14) as follows.

$AC_t = DC_t * \exp(implementation\ error * \text{i\_random})$……(14)

Implementation error is a fixed constant. i_random is the implementation random variable.

Assumed high-level observation error (setting as 0.6) and implementation error (setting as 0.5) in PCPP during its first-year trial and set recruitment variability as 0.6 for the theoretical *Portunus* crab, the average actual yield in relation to harvest rate on a monthly basis is demonstrated below.

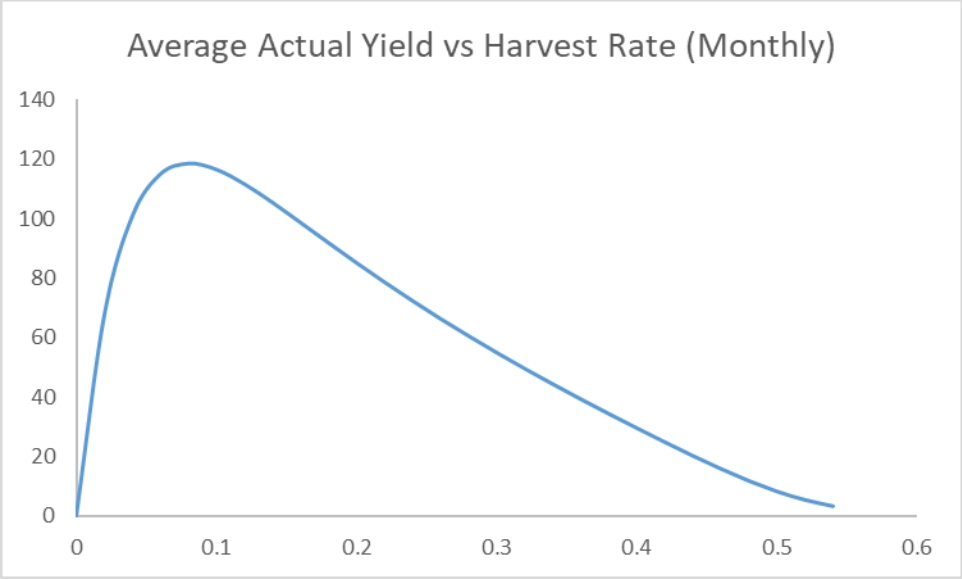

Figure 14: average yield in relationship to monthly harvest rate

4.4 PRELIMINARY PCPP MANAGEMENT STRATEGIES EVALUATION

Data deficiencies in the fisheries worldwide has posed a challenge to sustainable management of these species (Carruthers & Hordyk, 2018). Over 90% fish populations have limited data to support conventional fish stock assessment(Costello et al., 2012). An increasing recognition of improving management in data-limited fisheries management approaches has led to the emerging of alternative data-limited fisheries assessment methods in the recent years, including Data-limited Stock Synthesis (Cope, 2013), Catch-curve Stock Reduction Analysis (Thorson & Cope, 2015), etc. Carruthers et al. also applied a management strategies evaluation framework to evaluate data-limited methods for setting catch limits. In this chapter, the study uses the Data-Limited Fisheries Toolkit as alternative operating model to comparatively evaluate the performance of harvest strategies for PCPP. The Toolkit can be accessed online or installed via the CRAN-R repository or www.datalimitedtoolkit.com.

The Toolkit diagnoses a series of standardized data-limited methods based on the biological properties of *Portunus* crab species, PCPP's exploitation properties, observation error,

implementation error and other available types of data. The built-in Management Strategies Evaluation tests the performance of these methods over a simulated long period (i.e. 40 years) to prescribe the robust assessment outputs for the given stock and PCPP fishery context. Graphic outputs are illustrated for providing PCPP management implications.

Chapter 5. CONCLUSIONS

The thesis examines the *Portunus* crab fisheries pilot program on the ecological, human, and management subsystems. There are many ecological and fisheries characteristics identified in case studies. Both Indonesia and Australia identify environmental factors on *Portunus* crab fisheries management plan. The environmental factors such as water quality, water temperature, etc. influence the spatial distribution, morphological, and biological characteristics, which closely links with the success of *Portunus* crab management. The spatial distribution of *Portunus* crab is also shaped seasonally via these environmental factors, which fisheries managers in the PCPP should rethink about a stochastic zoning jurisdiction. The linkages between environmental factors and fisheries management factors highlight the importance of listing environmental factors into *Portunus* crab fisheries monitoring.

Table 6: Commodities, implications, and sources are tabulated

Commonalities	Implications	Case Sources
Causality exists with environmental variances are in in individual growth, size, and spawning potential.	Incorporate relevant environmental factors into the *Portunus* crab fisheries monitoring Rethink stochastic zoning approach	Indonesia Australia

Poor implementation compromises the management performance	Increase management capacity and policy compliance	Philippine
Geographic adjacency and species overlapping	Explore co-government on both sides of resource users	Taiwan

However, it could be a pervasive issue in the developing countries with respect to their capacity to effectively enforce their management measures. A well-established Blue Swimming Crab Plan in Philippine proves the importance of the concretizing processes from policy to implementation. As China has raised high policy support and multistakeholder efforts in PCPP initial stage, it is of significance to understand how to establish a well-managed fishery. The thesis highlights the data reporting and monitoring programs in the success of a managed fishery.

Taiwan and China have the closet adjacency in terms of close fishing ground, exploited species, and sociocultural context. However, there is little understanding with respect to what impacts Taiwanese fishing practices bring into the South Fujian and Taiwan Fishing Ground and what ecosystem-based perceptions is appropriate for *Portunus* crab fisheries management. To mitigate the uncertainties, the use of fish resources in the South Fujian and Taiwan Fishing Ground is expected to have the jointed collaboration between both parties.

With respect to challenges in PCPP fisheries system, the characteristics in PCPP's ecological, human, and management sub-systems shape its unique fishery context. There are six challenges categorized in accordance to PCPP sub-systems (Table 8). In the ecological subsystems, the thesis identifies the oversimplification of multispecies issues in PCPP management plan. In human subsystem, the thesis identifies no universal understanding among stakeholders with respect to the definition of a quota-based fisheries management system and misaligned stakeholder interests that

challenge the scientificity of establishing catch limits. The thesis also identifies "human dimensions" with respect to challenges of inadequate management capacity for PCPP policy implementation and institutional limitations for an unequal stakeholder participation in PCPP decision-making processes. But the underlying reason for two challenges. However, their existence is against stakeholders' willingness with underlying causes in the institutional loopholes. As a result, they are categorized into the management subsystem together with the challenge of the incompatibility issues between PCPP management plan and China's legislative framework.

Table 7: Challenges in PCPP Subsystems

PCPP subsystems	Challenges
Ecological subsystem	• Over-simplication of multispecies complexities in fisheries management
Human subsystem	• No universal understanding among stakeholders with respect to the definition of a quota-based fisheries management system • Misaligned stakeholder interests that challenge the scientificity of establishing catch limits
Management subsystem	• Inadequate management capacity for PCPP policy implementation • Institutional limitations for an unequal stakeholder participation in the decision-making process • Incompatibility issues between PCPP management plan and China's legislative framework

It can be noticeable that most challenges in PCPP's management come from the management subsystem. At its interim management practices, the challenges exist in the fisheries management design (i.e., unsafe fishing practices and disadvantaged socioeconomic benefits using Olympic-style fishing) and fisheries management basis (i.e., lacking enough management capacity and solid knowledge basis). Therefore, developing a better management system for *Portunus* crab fisheries is highlighted in this thesis research.

A multidimensional participatory assessment framework reflects the degree of performance with respect to the fulfillment of fisheries sustainability and the degree of understanding with respect to stakeholders understanding and the present data availability. Results are shown in Figure 15.

Dimensions	Indicators	Degree of Performance
Ecological	Exploitation status	Partially Understood
	Species changes	Partially Understood
	Vulnerability	Partially Understood
	Catch size	Partially Understood
	Catch before maturity	Partially Understood
	Bycatch	Partially Understood
	Migratory pattern	Partially Understood
Technological	Fleet capacity in relation to resource	Not Applicable
	Trend in catching power	Partially Understood
	Fishing gear side effects	Partially Understood
Socioeconomic	Infrastructure status	Fully Understood
	Extent of local ecological knowledge	Fully Understood
	Equity in fishing benefits	Not Completed
	Marketing system	Partially Understood
	Commoditization	Fully Completed
Ethical	Alternatives	Not Applicable
	Just governance	Partially Completed
	IUU fishing	Not Completed
Institutional	Policy support	Fully Completed
	Governance qualify	Not Completed
	Subsidies	Partially Completed

Fully Completed / Understood Partially Completed / Understood Not Completed / Understood Not Applicable

Figure 15: the assessment results of multidimensional participatory framework

The red grade represents a low level of degree of performance in fulfilling the operational definitions of the indicator or a low degree of understanding. The green grade represents in opposites with the red grade as the highest grade. The yellow grade stands in their middle. The grey grade indicates that the indicators are either ignored or not applicable in PCPP management. plan. The study observes limited understanding in ecological aspects, which limits the science capacity of TAC setting. The ignorance of equity in fishing benefits and the presence of IUU

In Chapter 4, a series of fisheries management strategies are examined as a preliminary application of applying data-limited toolkits into China's *Portunus* crab fishery (Figure 16).

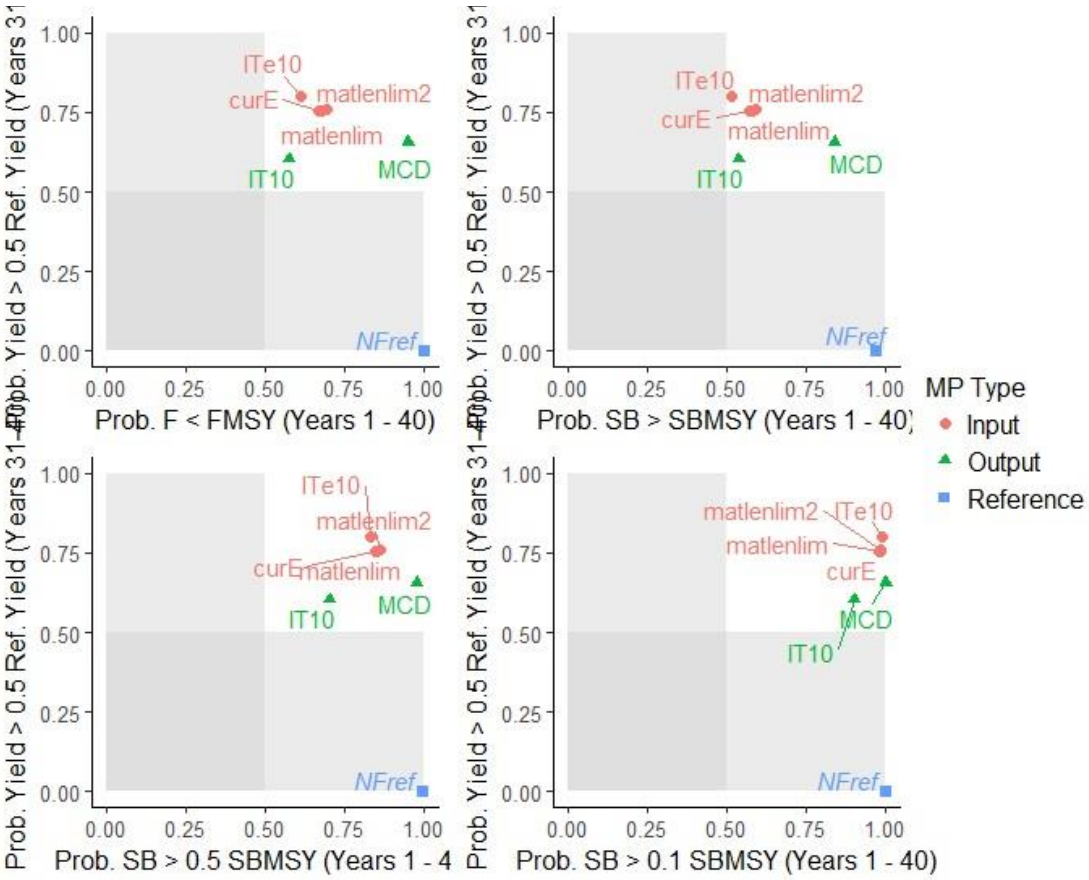

Figure 16: tradeoffs among different fisheries management strategies

The operational definitions of all management strategies are attached in the Appendix B. Here, the effort control (ITe10) should be noticeably identified as the most advantaged management strategy with respect to overfishing probability and the probability of spawning biomass preservation.

To overcome these challenges and deficiencies, the thesis proposes the recommendations. They are 1) developing an adaptative management planning grounded in the multifaceted aspects of the fishery system, 2) establishing new institutional mechanism for equal stakeholder participation in the decision-making process, 3) strengthening science-based fisheries management capacity toward a well-managed direction, 4) providing legal authority to enforce PCPP new management measures, 5) building consensus with consideration of stakeholder knowledge ground and alignment of interests, 6) understanding the ecological complexities of the PCPP fishery. The first definition intends to create an equity stakeholder participation scenario in the meanwhile defines China's marine fisheries sustainability in a broader scale. The other recommendations serve the interim management efforts and intend to establish a well-managed fishery as a good management basis.

Chapter 6. FUTURE WORK

The thesis recognizes the significance of establishing a quota-based fisheries management system as the first step toward China's marine fisheries paradigm. But recommendations are proposed in the analysis to improve the initial management practices in the PCPP. In the legislative perspective, China's national legal and subnational framework requires the continuous reform and innovations to mitigate the present incompatibility issues, strengthen legislative basis, and make fisheries regulation legally enforceable. In addition to quota system, alternative management strategies can

be explored on the basis of well-establishing a good fisheries management basis. A well-managed fisheries include higher-level management capacity, a systematic data collection, and monitoring systems. It requires the future efforts in improving institutional mechanism and rises the emphasis of concrete fisheries policy implementation, inspection, and monitoring. From a scientific perspective, future *Portunus* crab research is expected to be tutored by fisheries stock assessment principles. The research investigation may lead to the increase fisheries research transformation rates from scientific results into science-based fisheries management decisions. From the socioeconomic perspective, fisheries socioeconomic benefits should be incorporated into fisheries management objectives with concrete management measures. If PCPP ultimately enters into the catch share program, principles and rationales of quota allocation are generally based on the understanding of fisheries characteristics and intended socioeconomic benefits in the fisheries system. From the human-dimension perspective, equal stakeholder participation is expected to be considered with a more adaptative management mechanism. For example, it is open to discuss whether international NGOs could be a helpful source to provide capacity building in China's fisheries management.

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APPENDIX A- INTERVIEWEES

Interviewee	**Category**	**Identifier**	**Description**
1	Fisherfolk	F1	PCPP eligible fishing group
2	Fisherfolk	F2	
3	Fisherfolk	F3	
4	Fisherfolk	F4	
1	Academia	A1	Scientists and researchers engaging in the development, implementation, or evaluation of PCPP
2	Academia	A2	
3	Academia	A3	
4	Academia	A4	
1	Government	G1	Officials in PCPP fishery authorities
2	Government	G2	
1	Fishery Manager	M1	Officials commit to PCPP supervision, monitoring, and enforcement
2	Fishery Manager	M2	
1	NGO	N1	Employees in environmental NGOs participate in PCPP conferences or implementing *Portunus* crab fishery improvement project
2	NGO	N2	
3	NGO	N3	
4	NGO	N4	
1	Industry	I1	Employees in Fujian *Portunus* fishery industrial sectors
2	Industry	I2	

APPENDIX B – INTERVIEW TEMPLATE

Participation Eligibility Characteristics and Inclusion Criteria:

1. How old are you?

2. What is your job?

3. How does your job relate to *Portunus* crab fishery pilot program? (e.g. Professional Responsibilities; Engagement Time)

4. How long does your job relate to *Portunus* crab fishery?

Understanding of "Quota-based fishery management":

5. What is your definition of "Quota-based Management"? From your professional identity (defined as organization and roles in the fishery), what is the difference between your understanding and the policy interpretation regarding the meaning of this term?

Perception of Fujian Portunus crab pilot program:

6. What do you think of the management strategies in Fujian swimming crab pilot program? Any improvement suggestions?

Assessment methodology of Successful Pilot Program in Fujian's Portunus crab fishery:

7. From your professional identity, which indicators do you think can be used to reflect whether the implementation of quota-based management achieves the expected goals? Or to what extent do you think the quota-based management is successful?

Challenge Identification:

8. What do you think are the main difficulties in implementing quota-based management?

Influence Evaluation:

9. What positive or negative impacts do you think quota-based management may induce?

Scenario Projection:

10. What expectations or prospects do you have for the development of quota-based management in the future?

Role Identification:

11. What role / contributions do you think your organization / working department plays in the quota-based management system?

APPENDIX C – DEFINITIONS FOR MANAGEMENT PROCEDURES

SOURCE: R DOCUMENTARY IN DLM PACKAGE

1. F_{MAX} – fishing mortality that maximizes equilibrium YPR
2. $F_{0.1}$: The fishing mortality rate at which the slope of the yield-per-recruit curve is only one-tenth the slope of the curve at its origin.
3. FB40% is fishing mortality rate that leads to total spawning biomass to be 40% of what it would be in the absence of fishing (for a specific steepness value).
4. FMSY is fishing mortality rate which maximizes the yield from the system; it is conditional on selection pattern, schedules of growth and maturity, accuracy of stock-recruitment function, and other details
5. FSPR50%, FSPR40%, FSPR30%: the exploitation rate at SPR 50% SPR 40% and SPR 30%
6. SPR(n)% = SPR(n)/SPR(F=0)* 100%
7. ITe10: Index Target Effort-Based: the maximum fractional changes in total allowable effort is 10%
8. IT10: Iterative Index Target MP - maximum annual changes are 10% (TAC maximum allowable change in TAC is 10%)
9. cure: Fishing at current effort levels: set effort to 100% of that in final year of historical simulations
10. matlenlim: Size limit management procedures: fishing retention-at-length is set equivalent to the maturity curve
11. matlenlim2: Size limit management procedures: fishing retention-at-length is set slightly higher (110%) to the length-at-maturity curve
12. MCD: mean catch depletion (TAC=2*mean historical catch*estimate of current depletion): a simple average catch-depletion MP that was included to demonstrate just how informative an estimate of current stock depletion can be.
13. Nfref: reference management procedure: a reference MP that sets annual catch to almost zero (0.01)
14. ms60: size limits with 60mm size retention
15. ms70: size limits with 70mm size retention
16. ms80: size limits with 80mm size retention
17. ms90: size limits with 90mm size retention
18. ms100: size limits with 100mm size retention
19. ms110: size limits with 110mm size retention
20. ms120: size limits with 120mm size retention
21. CC uses a naïve catch curve extension to estimate current abundance based on catches and recent F
22. curE75: set effort to 75% of that in final year

23. CC1: TAC is average historical catch from recent yrsmth years
24. CC2: TAC is average historical catch from recent yrsmth years reduced by 10%.
25. CC3: TAC is average historical catch from recent yrsmth years reduced by 20%.
26. CC4: TAC is average historical catch from recent yrsmth years reduced by 30%.
27. CC5: TAC is average historical catch from recent yrsmth years reduced by 40%.
28. MPreal: Spatial closure and allocation management procedures. A spatial control that prevents fishing in area 1 and reallocates this fishing effort to area 2 (or over other areas).
29. MPnoreal: A spatial control that prevents fishing in area 1 and does not reallocate this fishing effort to area 2.
30. AvC_MLL: The average catch method is very simple. The mean historical catch is calculated and used to set a constant catch limit (TAC). If reps > 1 then the reps samples are drawn from a log-normal distribution with mean TAC and standard deviation (in log-space) of 0.2.