DISPERSAL OF CORAL LARVAE WITHIN INSHORE REEFS OF KUANTAN COASTAL WATERS

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy (Biosciences)

Kulliyyah of Science
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MAY 2020
ABSTRACT

Inshore reefs areas play several important ecosystem functions in marine environment especially in coastal area. Eight reef sites were surveyed using coral video transect (CVT) technique between April 2017 and April 2019 in Balok reef and Raja Muda reef to estimate coral reef benthic components. The timing of coral spawning of two Acropora species; Acropora cytherea and Acropora clathrata was estimated through dissection and histological analyses of coral fragments that were collected during predicted spawning months (March until May 2018) from Balok reef, Kuantan. In addition, physicochemical parameters (sea temperature, salinity and pH) were measured from March until September 2018 by multiprobe parameter. Satellite image was extracted between 2014 and 2018 from Aqua MODIS to observe seasonal pattern of sea surface temperature. Hydrodynamic model of Kuantan coastal water was simulated using MIKE 21 Flow Model FM and validated using 4 series of in situ current speed and direction data measured by Acoustic Doppler Current Profiler (ADCP) between August 2017 and April 2018. Dispersal pattern of coral larvae among three known inshore reefs (Pulau Ular, Balok Reef and Raja Muda reef) in Kuantan coastal waters was elucidated by simulating virtual larvae trajectories during spawning event in 2018. Dispersal pathways were modelled and constructed by incorporating biological traits (timing of spawning and pelagic larvae duration) using Lagrangian particle tracking module integrated with 2-dimensional, hydrodynamic, flexible network model (MIKE 21 FM). Dispersal Potential Index (DPI) was developed based on four important factors described throughout this thesis (adult coral cover, pelagic larvae duration, current speed and depth variation) to estimate dispersal potential capacity of coral larvae. Data analysis on coral reef benthic components indicated that Kuantan coastal waters has ‘fair’ coral cover with average percentage of 40.2 % ± 10.65 in which Angly 3 (ST3) recorded the highest live coral cover coverage with 50.3%. Abiotic components (sand and rock) were the second-most abundant and the coverage of dead coral was relatively low at all stations. Coral spawning observation of two Acropora species; Acropora cytherea and Acropora clathrata indicate spawning of these broadcast spawners occurred following full moon in April 2019. This finding confirmed histological examinations in the previous year (2018) that spawning for this genus might occur in April 2019. The gamete maturity coincided with the peak sea surface temperature within Kuantan coastal waters from April until May 2018. Optimal pelagic larvae duration for these species were estimated to be between 6 – 8 days after spawning. Hydrodynamic model indicated the prevalence of tidal forcing in influencing current flow in Kuantan coastal region rather than seasonal changes by monsoonal winds. Virtual larvae simulation indicated Pulau Ular has high larvae retention (76 %) in which most of larvae originated from natal reef. Balok reef was dominant source of larvae for Raja Muda reef. Results also indicated that patches reefs near Raja Muda was ideal sink site for coral larvae and should be prioritized for future ecosystem management action. It is believed that findings from this research could give reliable scientific on dispersal of coral larvae within inshore reefs of Kuantan coastal waters.
خلاصة البحث

تلعب مناطق الشعاب المرجانية الداخلية العديد من وظائف النظام البيئي الهامة في البيئة البحرية وخاصة في المناطق الساحلية. تم تسجيل ثمانية مواقع للشعاب المرجانية باستخدام تقنية مقطعية الفيديو المرجانية (CCTV) في أبريل 2017 وأبريل 2019 في شعاب منطقة بالوء، راجا مودا Acropora clathrata و Acropora cytherea لتقييم مكونات قاع الشعاب المرجانية. تم تقييم تفريخ المرجان لاعبين من خلال التشريح والتحليلات النسيجية Acropora clathrata و Acropora cytherea؛ للشظايا المرجانية التي تم جمعها خلال أشهر التفريخ المتوقعة (أذار حتى حزيران 2018) من بلوك ريف ، كوتان. بالإضافة إلى ذلك، تم قياس المعلمات الفيزيائية الكيميائية (درجة حرارة البحر والملوحة ودرجة الحمضية) من مارس حتى سبتمبر 2018 بواسطة معلمات متعددة. تم استخدام الصوتي (ADCP) في شعاب المرجانية الساحلية المعروفة (شعاب بالوء أوراول وبلوك ريف وراجا مودا) في المياه الساحلية في كوتان من خلال محاكاة مسارات اليرقات خلال عملية التفريخ في عام 2018. تم تصميم وتنبؤ التنبؤات والتفاحات من خلال مقياس البيولوجي (توفيق نمط التفريخ) باستخدام وحدة تتبع الصوتي (Lagrangian). 

شبكة ثمانية الأعداد، هديوديناميكية مرن (MIKE 21 FM) تم تطوير مؤشر الفترة التنشيطية استنادًا إلى أربعة عوامل مهمة تم وصفها طوال هذه الرسالة (الطقس المرجاني للبالغين، وحدة اليرقات البحرية، السرعة الحالية، وارتفاع العمود) لتقييم السعة المحتملة لإنشاء اليرقات المرجانية. أظهرت التحليل البياني عن مكونات قاع الشعاب المرجانية إلى أن المياه الساحلية في كوتان لها غطاء مرجاني "عادل". بمتوسط نسبة 40.2 % ± 6.55 مسجلك فيها على تغطية المرجانية حسب نسبة 50.3% كانت النموذجات في الحيوية Angly 3 (ST3) (الرمل والصخور) هي ثاني أكثر وفرة وكانت تغطية الشعاب المرجانية المنخفضة بنسبة في Acropora clathrata. 

جميع المحطات. تم رصد تكاثر المرجان ليوتين من 10.65 ملم إلى 10.7 ملم قبالة راجا مودا في نيسان 2019. أدركت نتائج البحوث النسيجية في العام السابق (2018) أن التفريخ لهذا الجنس قد يحدث في نيسان 2019. يتزامن نضج الأشواج مع فترة تفريخ ساحلية داخل المياه الساحلية في كوتان حتى حزيران 2019. قد تغير مدى عمق المرجان المثلث لدى الأنواع ما بين 6 - 8 أيام بعد التفريخ. أشار النموذج الهيدروميكانيكي إلى انتشار تأثير الماء والجزر في التأثير على التدفق الحالي في المنطقة الساحلية في كوتان بدلاً من التغيرات الموسمية بفعل الرياح الموسمية. أشارت محاكاة اليرقات الافتراضية إلى أن بلوك أولار لديها احتكاك كبير لليرقات 76 % حيث نشأت معظم اليرقات من الشعاب الأموية. كانت الشعاب المرجانية المنطقية بالوأولار مصدر اليرقات الساحنة في ريف راجا مودا. كما أشارت التنبؤات إلى أن بقع الشعاب المرجانية بالقرب من راجا مودا كانت موقعًا ثانويًا لغرق اليرقات المرجانية ويجب منحها الأولوية لعمل إدارة النظام البيئي في المستقبل.
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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, Most Merciful. All praise to Him for giving me strength throughout my PhD journey and guidance in facing obstacles while completing this thesis. I would like to express my gratitude to everyone who involve directly or indirectly during this research, especially to Department of Biotechnology, Kulliyyah of Science and of course, Department of Marine Science for continuing support my research work.

Millions of thanks and appreciation to my supervisor, Prof. Dr. Shahbudin Saad and my co-supervisor, Asst. Prof. Dr. Zuhairi Ahmad for encouragement, guidance and wisdom throughout this research. The learning process will never end here, and I am forever indebted to you for all the knowledge that you have shared with me. Both of you were indeed among the best personnel I ever worked with.

This research will never be completed without never-ending and tireless support from my beloved wife, Najma Tasnim Mohamad. Thank you for always being there for me during ups and downs at certain stages in my study. To my lovely sons; Nawfal, Naqib and Nadzmi, you are indeed my greatest strength and motivation in completing this research. I would also like to thank my beloved parent and sisters for their understanding.

My sincere appreciation also extends to the staff of Kulliyyah of Science especially Br. Khairul, Br. Azizul, Br. Muzammil, Br. Masrul, Br. Azwan and Sr. Noorshamriza for helping me throughout the research. Thank you to my Head of Department, Asst. Prof. Dr. Nur Nazifah Mansor for encouragement and support. I would also like to thank Dr. Mohd Fuad Miskon, Head of INOCEM for giving me full support and cooperation during data collection and my fellow Academic Trainee, Dr. Zaini and Dr. Fitri for giving me advices in completing my PhD. Special thanks to my colleagues from Remote Sensing & GIS Lab, Sr. Suhaila and Br. Shaheed for providing me assistance and consultation for biophysical modelling application and SeaQuest diving team, Br. Hamizan and Br. Fikri Akmal for helping me to conduct samplings. This project was funded by E-science Fund under Ministry of Energy, Science, Technology, Environment and Climate Change Malaysia (SF16-002-0071). Jazakallah.
TABLE OF CONTENTS

Abstract .......................................................................................................................... ii
Abstract in Arabic ......................................................................................................... iii
Approval Page ............................................................................................................... iv
Declaration ................................................................................................................... v
Copyright Page ........................................................................................................... vi
Acknowledgement ....................................................................................................... vii
Table of contents ........................................................................................................ viii
List of Tables ................................................................................................................ xii
List of Figures .............................................................................................................. xiv
List of Abbreviations .................................................................................................. xvi

CHAPTER ONE: INTRODUCTION ................................................................................. 1
  1.1 Research Background ......................................................................................... 1
  1.2 Problem Statement .............................................................................................. 3
  1.3 Significances of Study ....................................................................................... 5
  1.4 Hypotheses ......................................................................................................... 5
  1.5 General Objectives of Study ............................................................................. 6

CHAPTER TWO: LITERATURE REVIEW ................................................................. 7
  2.1 Regional Coral Reef Status ................................................................................. 7
  2.2 Reproductive Biology and Coral Spawning Pattern .......................................... 8
    2.2.1 Reproductive Strategies of Scleractinian Coral ........................................... 8
    2.2.2 Coral Spawning Pattern ............................................................................. 11
    2.2.3 Environmental Cues Regulating Timing of Reproduction ....................... 13
      2.2.3.1 Sea Surface Temperature .................................................................. 13
      2.2.3.2 Lunar Cycle ....................................................................................... 14
  2.3 Regional Marine Environment .......................................................................... 15
    2.3.1 Regional Sea Surface Temperature .......................................................... 15
    2.3.2 Wind .......................................................................................................... 16
    2.3.3 Tidal pattern ............................................................................................... 17
    2.3.4 Current ........................................................................................................ 17
  2.4 Dispersal of Coral Larvae in Marine Metapopulation ......................................... 19
    2.4.1 Connectivity in the Coral Reef Ecosystem ............................................... 19
    2.4.2 Biological Factors in Coral Larvae Dispersal ........................................... 20
      2.4.2.1 Pelagic Larvae Duration .................................................................. 20
      2.4.2.2 Timing of Spawning and Larvae Release ......................................... 21
      2.4.2.3 Vertical and Horizontal Dispersion of Coral Larvae ....................... 22
  2.5 Multi-dynamic Approaches in Elucidating Coral Larvae Dispersal Pattern .......... 23
    2.5.1 Techniques in Measuring Larval Dispersal .............................................. 23
      2.5.1.1 Population Genetics .......................................................................... 23
      2.5.1.2 Direct Tracking and Artificial Markers ........................................... 24
2.5.1.3 Numerical Modelling ........................................... 25
2.5.2 Biophysical Modelling Application in Dispersal of Coral Larvae ........................................... 25

CHAPTER THREE: GENERAL METHODOLOGY .................. 27
3.1 Introduction ............................................................ 27
3.2 Description of Study Area ........................................ 27
3.3 Methodology Applied in The Study ............................ 29

CHAPTER FOUR: CORAL DISTRIBUTION IN KUANTAN COASTAL WATERS ........................................... 34
4.1 Introduction ............................................................ 34
4.2 Methodology .......................................................... 36
  4.2.1 Study Area .......................................................... 36
  4.2.2 Measurement of Physicochemical Parameters .......... 38
  4.2.3 Coral Video Transect Survey ................................ 38
  4.2.4 Video Transect Post-Data Processing ................... 39
  4.2.5 Data Analysis ...................................................... 42
4.3 Results ................................................................. 42
  4.3.1 Physicochemical parameters in Kuantan coastal waters 42
  4.3.2 Benthic Community Structure in Kuantan Coastal Waters 43
4.4 Discussion ............................................................. 48
  4.4.1 Coral Condition in Kuantan Coastal Waters .......... 48
  4.4.2 Physicochemical Influences on Coral Distribution Pattern 48
  4.4.3 Coral Adult Spatial Distribution Influence on Larval Pool 50
4.5 Conclusion ............................................................ 51

CHAPTER FIVE: BROADCAST SPAWNING PATTERN AND PELAGIC LARVAE DURATION OF ACROPORA CYTHEREA AND ACROPORA CLATHRATA FROM INSHORE REEF AREA IN KUANTAN COASTAL WATERS ........................................... 52
5.1 Introduction ............................................................ 52
5.2 Methodology .......................................................... 53
  5.2.1 Study site .......................................................... 53
  5.2.2 Temporal Variation in Environmental Cues for Coral Spawning .............................................. 54
  5.2.3 Histology Analysis for Coral Spawning Prediction .... 55
    5.2.3.1 Sample collection ........................................... 55
    5.2.3.2 Sample Preparation ....................................... 56
    5.2.3.3 Tissue processing and histological examination .... 56
  5.2.4 Coral Spawning Observation of Acropora cytherea and Acropora clathrata ..................................... 59
  5.2.5 Pelagic Larvae Duration Estimation for A. cytherea and A. clathrata ............................................. 61
    5.2.5.1 Coral larvae collection ................................... 61
    5.2.5.2 Estimation of optimum pelagic larvae duration .... 61
7.2.2.3 Dispersal model simulation .............................................. 103
7.2.2.4 Data extraction .......................................................... 103

7.3 Results .................................................................................. 105
  7.3.1 Dispersal Pattern of Coral Larvae ..................................... 105

7.4 Discussion ............................................................................. 112
  7.4.1 Dispersal Pattern of Coral Larvae in Kuantan Coastal Waters ..... 112
  7.4.2 Source and Sink Dynamic Pattern of Coral Larvae in Kuantan Coastal Waters ................................................................. 114
  7.4.3 Implications of Dispersal Pattern for Ecosystem Management .... 115
  7.4.4 Limitation of Dispersal Model Simulations ......................... 116
  7.4.5 Dispersal Potential Index as Indicator for Coral Larvae
    Dispersal Capacity ................................................................ 117
    7.4.5.1 Factors Which Influence Dispersal Capacity ................. 117
    7.4.5.2 DPi Score Chart ........................................................... 118
    7.4.5.3 Application of DPi for Reef Managers ......................... 120

7.5 Conclusion ............................................................................. 122

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATION ........... 124
  8.1 Conclusion ......................................................................... 124
  8.2 Recommendations .............................................................. 126

REFERENCES ............................................................................. 128

APPENDIX A: PUBLICATIONS AND CONFERENCES .................. 143
APPENDIX B: INSTRUMENTS USED IN THIS STUDY .................... 144
APPENDIX C: SUPPLEMENTARY MATERIALS ............................ 146
LIST OF TABLES

Table 2.1 Recent Studies Using Biophysical Modelling
Table 4.1 Reef Sites Coordinates Surveyed in The Study
Table 4.2 Coral Reef Benthic Components
Table 4.3 Coral Genera Codes Applied in CPCe Analysis
Table 4.4 Coral Reef Health Criteria
Table 4.5 Physicochemical Data in Balok Reef
Table 4.6 Current Speed Recorded in Balok Reef
Table 4.7 ANOVA Test Analysis for Coral Reef Benthic Components
Table 4.8 Distribution of Coral Genera Based on Reef Sites
Table 5.1 Harris’s Hematoxylin and Eosin Staining Protocol
Table 5.2 Physicochemical Data Recorded in The Study Area
Table 5.3 ANOVA Test Analysis for Annual SST
Table 5.4 ANOVA Test Analysis for Salinity
Table 5.5 ANOVA Test Analysis for Annual SST
Table 5.6 ANOVA Test Analysis for Mean Oocytes Count Per Polyp
Table 5.7 ANOVA Test Analysis for Mean Number of Newly Settled Larvae
Table 6.1 Survey Activities and Schedule
Table 6.2 Hydrodynamic Model Setup
Table 6.3 Computed RMSE for Surface Elevation
Table 6.4 Computed RMSE for current speed and direction
Table 6.5 Statistical Analysis from Hydrodynamic Model Simulation
Table 6.6 Statistical Analysis for Data Input and Output
Table 7.1 Relative Settlement Percentage Pattern of Acroporid Larvae
Table 7.2 Directional Dispersal Pattern Between Populations 111
Table 7.3 Summary of Score for Factors Considered in DPi 119
Table 7.4 Proposed Score Values for DPi Range 119
Table 7.5 Dispersal Factor Score Comparison 120
LIST OF FIGURES

Figure 2.1 Coral Reproduction Cycle 11
Figure 2.2 Surface Current Pattern in The South China Sea 18
Figure 3.1 Location of Study Area 28
Figure 3.2 Flow Chart of Methodology for Chapter Four 29
Figure 3.3 Flow Chart of Methodology for Chapter Five 31
Figure 3.4 Flow Chart of Methodology for Chapter Six 32
Figure 3.5 Flow Chart of Methodology for Chapter Seven 33
Figure 4.1 Location of Study Area in Kuantan Coastal Waters 37
Figure 4.2 Image Processing Using CPCe Software 40
Figure 4.3 Mean Percentage Cover of Coral Reef Benthic Components 44
Figure 4.4 Mean Percentage Cover of Live Coral Categories (LC) 45
Figure 4.5 Mean Percentage Cover of Dead Coral Categories (DC) 45
Figure 4.6 Mean Percentage Cover of Other Invertebrate Categories (OT) 46
Figure 4.7 Mean Percentage Cover of Abiotic Categories (AB) 46
Figure 5.1 Location of Study Sites 54
Figure 5.2 Coral Colonies Of a) Acropora cytherea and b) Acropora clathrata 56
Figure 5.3 Mature Oocyte Observed from Acropora cytherea 59
Figure 5.4 Coral Larvae Trap Which Attached to Acropora Colony. 60
Figure 5.5 Crustose Coralline Algae (CCA) 62
Figure 5.6 Pelagic Larvae Duration Estimation for Using 6-Well Culture Plate 63
Figure 5.7 Mean Annual Sea Surface Temperature (SST) from 2014 until 2018 65
Figure 5.8 Mean Oocytes Count Per Polyp for Acropora cytherea. 66
Figure 5.9 Mean Oocytes Count Per Polyp for Acropora clathrata 67
**LIST OF ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCP</td>
<td>Acoustic doppler current profiler</td>
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<tr>
<td>CCA</td>
<td>Crustose coralline algae</td>
</tr>
<tr>
<td>CPCe</td>
<td>Coral Point Count with Excel extension</td>
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<tr>
<td>CVT</td>
<td>Coral video transect</td>
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<td>DAS</td>
<td>Days after spawning</td>
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<tr>
<td>DHI</td>
<td>Danish Hydraulic Institute</td>
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<td>Dpi</td>
<td>Dispersal Potential index</td>
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<tr>
<td>ECMWF</td>
<td>European Centre for Medium-Range Weather Forecasts</td>
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<tr>
<td>GEBCO</td>
<td>General Bathymetry Chart of the Ocean</td>
</tr>
<tr>
<td>H &amp; E</td>
<td>Hematoxylin and Eosin</td>
</tr>
<tr>
<td>JPS</td>
<td>Jabatan Pengairan dan Saliran</td>
</tr>
<tr>
<td>Ppt</td>
<td>Part per thousand</td>
</tr>
<tr>
<td>MPA</td>
<td>Marine protected area</td>
</tr>
<tr>
<td>NAFM</td>
<td>Night after full moon</td>
</tr>
<tr>
<td>NEM</td>
<td>Northeast Monsoon</td>
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<tr>
<td>PLD</td>
<td>Pelagic larvae duration</td>
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<tr>
<td>RMSE</td>
<td>Root mean square error</td>
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<tr>
<td>SEM</td>
<td>Southeast Monsoon</td>
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<tr>
<td>SST</td>
<td>Sea surface temperature</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
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CHAPTER ONE
INTRODUCTION

1.1 RESEARCH BACKGROUND

The fluid nature of marine environment provides a variety of ways for its ecosystem components to disperse within and among the population. The movement of water in a certain surface current pattern may act as the main transporter for marine organisms from one place to another, causing interchange of individuals between populations in a different habitat. This demographic linking of the local population through dispersal is known as connectivity and a fundamental process that influence the dynamic of many marine ecosystems (Sale et al., 2005; Werner et al., 2001). Connectivity is highly regarded as a key conservation objective due to its role in shaping population persistence and resilience (Grimsditch & Salm, 2006; Roberts et al., 2006). Exchange of individuals in the marine realm enable species to spread to different habitats (Hawkins et al., 2015), relocate ecological components which have been impaired by disturbances (Cowen et al., 2006) and permit genetic mixing among meta-populations (Palumbi, 2003). More attentions are given towards issues pertaining connectivity in the past decade driven by shifting focus towards fisheries resource management, the spread of invasive species, designation of marine protected areas and also forecasting climate change impact on the marine ecosystem (Levin, 2006).

Connectivity plays a vital role in sessile marine invertebrate ecology. For non-migratory organisms such as coral reef which physically attached to the substrate, connectivity relies heavily on dispersal of coral larvae. Coral life cycle involves benthic polyp phase and planula larval phase. Broadcasting coral such as Acropora,
which encompasses most coral species release larvae into the water column during mass spawning season. During this early life stage, most of the coral larvae are unable to swim horizontally to reach settlement sites and thus depend on the prevailing current as main dispersal transport. These larvae may disperse in an extensive range of distance from a few meters to hundreds of kilometers before successful settlement depending on the current pattern during planktonic stage (Cowen et al., 2006).

Numerous approaches were applied to elucidate coral larval dispersal pattern and meta-population connectivity. Earlier efforts implied on direct larval tracking which proven to be labor intensive and cost inefficient (Willis & Oliver, 1990). Empirical approaches to quantify dispersal and connectivity are very challenging due to the small size of larvae which are being transported in the enormous and complex ocean environment (Cowen & Sponaugle, 2009). For instance, larval dispersal pattern in the field was tracked with tagging dyes and satellite-tracked drifters (Lugo-Fernández et al., 2001; Almany et al., 2007). These approaches were not practical since dyes diminish after a certain period while drifters tend to be lost or damaged during tracking. Apart from that, there were several attempts to describe dispersal pattern by using population genetic approaches and produce a promising unambiguous experimental estimation of larval dispersal. Despite these approaches, comprehensive information about larval dispersal pattern is still lacking and insufficient (Green et al., 2015).

Hence, ecologist has now switched to indirect methods as alternatives to study larval dispersal. Dispersal pattern of coral larvae is investigated using hydrodynamic models’ simulation and numerical modeling to describe particle transport and to estimate the number of larvae that may arrive at certain reef locations. These models regularly predict great degree of connectivity among the marine population.
Numerical modeling could produce incomparable insight on population connectivity and larval dispersal (Werner et al., 2001). Estimation on potential connectivity pattern between separate populations can be done in a wider range of spatial and temporal scales compared to direct empirical approaches (Botsford et al., 2009). Modeling of larval dispersal pattern also gives us the ability to envisage effect of natural changes in the environment on connectivity such as a change in circulation pattern and sea surface temperature variation (Cowen & Sponaugle, 2009).

Computational modeling of current pattern has advanced rapidly in terms of spatial and temporal resolution since the 1980s (Werner et al., 2001; Kinlan et al., 2005). Coupled with Eulerian or Lagrangian modules, these models evolved from two-dimensional models to more complex three-dimensional one in tracking the movement of larvae particles. The lagrangian method was described by Jongejans et al., (2008) as individual trajectories of particle tracking in the water while Eulerian implies on trailing the particles movement as an entire parcel/volume. Between these modules, the Lagrangian methods have been more widely used in larval dispersal.

1.2 PROBLEM STATEMENT
Kuantan coastal waters has several patches of inshore reefs such as those in Pulau Ular in the north, Balok reef in the middle and Raja Muda reef in the south. These reefs are pristine yet remain vulnerable from various anthropogenic influences such as sedimentation and nutrient enrichment due to its close proximity to the mainland. Previous study by Husaini et al. (2015) has recorded 33 coral genera from 13 families at 3 reef sites in Balok alone while Sidek (2016) reported 36 coral genera from 13 families in Pulau Ular. Husaini et al. (2015) also reported new recruits arrived at Balok reef from 10 different coral genera. Whether those new recruits originated from
the natal reef or neighboring reef remain unknown. This has emphasized further investigation in determining the source and sink reef pattern through coral larvae dispersal study. To date, less documented data available for dispersal of coral larvae in Malaysia since research were focused on coral diversity (Harborne et al., 2000; Toda et al., 2007; Shahbudin et al., 2017).

Study on dispersal of coral larvae is crucial for better ecosystem management. Understanding the factors behind dispersal and estimation of dispersal distance would assist researchers and government agencies to estimate optimal size and location of potential marine protected areas (Levin, 2006). Assessing source and sink pattern of larvae in certain reef area is vital because repopulation of habitats affected by disturbances was achieved through larvae dispersal. In general, the ability of coral larvae disperses from its natal reef rely on the local hydrodynamic pattern during spawning activities. Dispersal pattern also influenced by physiological and early life history of the larvae such as longevity, responses to natural inducer for metamorphosis, rates of mortality and also optimal pelagic larval duration (Heyward & Negri, 1999; Nozawa & Harrison, 2002; Harii & Kayanne, 2003; Graham et al., 2013).

Recently, there is increasing attention given in incorporation of physical models and the biological variables of the larvae which better known as biophysical models. The inclusion of certain biological processes during dispersal such as pelagic larval duration, larval release from source reef, larval mortality and larvae settlement onto reef habitat in the models give an explicit picture on reef connectivity. Even though information on these biological processes are still limited especially among coral reef species, larval dispersal virtual simulation has been proven to be able to
forecast population connectivity with adequate precision for conservation and management purpose (Tilburg et al., 2010).

1.3 SIGNIFICANCES OF STUDY

Findings from this research could give reliable scientific data in describing dispersal of coral larvae in Kuantan coastal waters. This research could give a better understanding in the dispersal of coral larvae in the study area by incorporating hydrodynamic pattern and larval physiological properties through the application of the biophysical model for effective ecosystem management. Apart from that, the present study introduced Dispersal Potential index (DPI) based on the multi-dimensional factors which may affect dispersal distance for coral larvae. The strength of DPI for coral larvae could determine their general dispersal range and these key elements are important for future ecosystem management. Therefore, it is believed this research could produce crucial information to estimate the ability of reef to recover from any disturbances, be it from natural or anthropogenic.

1.4 HYPOTHESES

There are four important hypotheses investigated in this study.

I. Inshore reefs in Kuantan coastal waters might be dominated by stress-tolerant genera due to proximity with the Kuantan coastal area.

II. Broadcast spawning pattern of *Acropora* might be influenced by seasonal variation of sea temperature.

III. Tidal pattern might give greater influence on ocean circulation pattern in Balok reef due to proximity to the mainland.
IV. Inshore reefs in Kuantan coastal waters might be connected in source-sink dynamic population connectivity.

1.5 GENERAL OBJECTIVES OF STUDY

The specific objectives of this research are as follows:

I. To assess coral distribution pattern in several reefs area in Kuantan coastal waters.

II. To determine broadcast spawning pattern and estimate pelagic larvae duration of hard coral from genus *Acropora*.

III. To establish and validate a fine scale hydrodynamic base model for Balok reef.

IV. To describe the dispersal pattern of coral larvae in Kuantan coastal waters.
CHAPTER TWO
LITERATURE REVIEW

2.1 REGIONAL CORAL REEF STATUS

There has been increasing number of documented studies on the current status of coral reef in the east coast of Peninsular Malaysia such as those in Tioman Island and Redang Island for the past five years (Shahbudin et al., 2017; Akmal et al., 2019). However, present evident clearly indicated that coral reefs are subjected with habitat degradation due to human activities such as pollution discharge, increased sedimentation as a result of unsustainable coastal development and overfishing (Pandolfi et al., 2003; Browne et al., 2010; Guest et al., 2016). Apart from that, series of mass coral bleaching event caused by global warming which occurred in 1998, 2002 and 2016 has caused the major coral death for coral (Hughes et al., 2018).

Inshore reefs are fringing reefs which located less than 20 km from the shoreline (Heery et al., 2018). Due to rapid urbanization in coastal zones in this region, inshore reefs might be exposed to anthropogenic stressors such as increased sedimentation, nutrients and pollution influx as suggested by Heery et al. (2018) which are detrimental to coral reef. Extensive review on the status of inshore reefs in highly urbanized coastal area from 11 cities throughout East and Southeast Asia highlighted the impact of coastal development on morphology, distribution and community composition pattern of these so-called urban reef (Heery et al., 2018). They also pointed out that reef may be compressed (reduced in average percentage cover) due to increased sedimentation and may dominated by massive growth form (Heery et al., 2018). Previous coral survey in inshore reefs at the west coast of
Peninsular Malaysia by Safuan et al. (2016) and Crehan et al. (2019) reported relatively poor coral condition (having less than 25% average percentage cover) in highly urbanized coastal area. Both studies implied that high sedimentation and anthropogenic stress which hindered coral growth and development. On the contrary, recent coral community survey in 5 inshore reef sites near Balok area which located at the east coast of Peninsular Malaysia by Hanapiah et al. (2019) suggested that reef condition was considered as fair with average percentage cover of 39%. This has indicated that some reef may still thrive although in relatively high suspended sediment condition. Such pattern also has been observed by Browne et al. (2010) who reported fair coral cover (39%) in Middle Reef central Great Barrier Reef which has high suspended sediment due to proximity with urbanized area. These findings also highlighted the importance of coral monitoring in the inshore reefs area in order to obtain better assessment on coral distribution and could estimate the impact of future coastal development on reef ecosystem.

2.2 REPRODUCTIVE BIOLOGY AND CORAL SPAWNING PATTERN

2.2.1 Reproductive Strategies of Scleractinian Coral

Scleractinian corals or hard coral are among the most broadly studied marine modular organisms (Baird et al., 2009). It was estimated that approximately 800 out of 1400 known species were colonial (Cairns, 1999) in which each colonial organism is comprised of interdependent individuals with its own birth and death rate (Baird et al., 2009). Understanding reproductive biology of coral is among the important aspect in coral larvae dispersal study. The mode of reproduction (sexual, asexual, hermoproditism, gonochoricsm and brooding) dictate the dispersal pattern of coral