

STOCK ASSESSMENT AND POPULATION  
DYNAMICS OF *Plectropomus pessuliferus*  
AND *Plectropomus areolatus* IN THE  
SUDANESE RED SEA COAST

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DOCTOR OF PHILOSOPHY  
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**Thesis Submitted in Fulfillment of the  
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and Aqua-Industry  
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# DEDICATION

*To my late father*

*To my wife, the late (Suzan)*

*To my mother*

*To my wife and kids*

*To my brothers and sisters*

*To my friends*

Abstract of thesis presented to the Senate of Universiti Malaysia  
Terengganu in fulfillment of the requirement for the Degree of Doctor of  
Philosophy

**STOCK ASSESSMENT AND POPULATION DYNAMICS OF  
*Plectropomus pessuliferus* AND *Plectropomus areolatus* IN THE  
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The coralgroupers, *Plectropomus pessuliferus* and *Plectropomus areolatus*, which are known locally as "Najil" and "Silimani", respectively, have been the main target species for artisanal fishermen in Sudanese marine fisheries for the past two decades. In general, these two species are long-lived and slow growing with low rates of natural mortality. They are protogynous species, having the tendency to form spawning aggregations, which makes them more vulnerable to fishing.

However, not much information is available on the population biology of these two species in Sudan to assist in their management and sustainable exploitation. Therefore, some aspects of the biology and

population dynamics of the *P. pessuliferus* and *P. areolatus* distributed in two locations in Sudanese Red Sea coast were investigated from August 2009 to November, 2010.

A total of 213 and 165 specimens of *P. pessuliferus* with sizes ranging from 300-900 mm and 272 and 262 specimens of *P. areolatus* with sizes ranging from 245-775 mm were sampled from Dungonab Bay and Mukkawar Island National Park (DBNP) and Suakin, respectively. All fish samples were collected monthly for determination of the reproductive biological characteristics, growth parameters, mortality rates, and yield per recruit and biomass per recruit. In addition to two fishing experiments in the two locations to determine the catch and CPUE, archived data from Fisheries Administration and trader's records were analyzed to examine the status of two species and propose a suitable management for fisheries of the *P. pessuliferus* and *P. areolatus* distributed in two locations. The mean CPUE around Suakin was 2.04 kg per hour and 1.20 kg per fisherman; CPUE for DBNP was 4.08 kg per hour and 2.49 kg per fisherman. The mean CPUE for *P. areolatus* is higher than *P. pessuliferus* in the two locations. The overall female-male sex ratios for all species were significantly different from 1:1. There is a clear histological evidence of sex change in *P. pessuliferus* and *P. areolatus*. The seasonal distribution of maturity stages and fluctuations gonadosomatic index (GSI), questionnaire

results, archived data for the catch, and trader's records indicated that the spawning season for *P. pessuliferus* can be determined in DBNP from March to July and in Suakin from March to May; while the spawning season of *P. areolatus* from DBNP took place from May to July, from Suakin appeared April to June.

Length at first maturity ( $L_m$ ) for *P. pessuliferus* from DBNP was 57.2 cm and 61.4 cm total length for females and males respectively, for *P. pessuliferus* from Suakin  $L_{50}$  were 57.4 cm and 64.5 cm total length for females and males respectively.  $L_{50}$  for *P. areolatus* from DBNP were 45.3 cm and 47.4 cm total length for females and males respectively, for *P. areolatus* from Suakin  $L_{50}$  were 42 cm and 43.3 cm total length for females and males respectively. The length at sex change ( $L_s$ ) for *P. pessuliferus* from DBNP was 67.9 cm total length for females to change to males, for *P. pessuliferus* from Suakin  $L_s$  was 74.9 cm total length for females to change to males.  $L_s$  for *P. areolatus* from DBNP was 50.3 cm total length for females to change to males, for *P. areolatus* from Suakin  $L_s$  was 47.1 cm total length for females to change to males respectively. The absolute fecundity was found for *P. pessuliferus* at DBNP between  $5.8 \times 10^5$  -  $8.0 \times 10^6$  eggs with mean of  $2.3 \times 10^6$  eggs per mature female, while for *P. pessuliferus* at Suakin found to be  $5.8 \times 10^5$  -  $3.4 \times 10^6$  eggs with mean of  $1.3 \times 10^6$  eggs per mature female. For *P.*

*areolatus* at DBNP, the absolute fecundity was  $5.9 \times 10^5$  -  $4.1 \times 10^6$  eggs with mean of  $1.6 \times 10^6$  eggs per mature female.

Vertebrae and sagittal otoliths of two species in two locations were removed and examined for determination age structure of the fish stock. Each otolith is bony, concave and elliptical; the convex surface of each otolith is oriented towards the central axis of the fish. The vertebrae and otoliths clearly showed annuli as opaque zones that appeared darker than the adjacent hyaline or translucent zones. Ten and eleven age groups were identified for *P. pessuliferus* at DBNP and Suakin respectively; while eight and six age groups were identified for *P. areolatus* at DBNP and Suakin respectively.

The parameters of Von Bertalanffy growth equation were obtained for *P. pessuliferus* and *P. areolatus* at DBNP and Suakin, the equations as showed below:

$$\text{For } P. \textit{pessuliferus} \text{ at DBNP; } L_t = 116.836 [1 - e^{(-0.120 [t - (-2.45)])}]$$

$$\text{For } P. \textit{pessuliferus} \text{ at Suakin; } L_t = 122.194 [1 - e^{(-0.112 [t - (-2.59)])}]$$

$$\text{For } P. \textit{areolatus} \text{ at DBNP; } L_t = 88.725 [1 - e^{(-0.143 [t - (-2.49)])}]$$

$$\text{For } P. \textit{areolatus} \text{ at Suakin; } L_t = 79.273 [1 - e^{(-0.163 [t - (-2.55)])}]$$

The total mortality based on catch curve analysis gave the values  $0.7460 \text{ yr}^{-1}$  and  $0.7466 \text{ yr}^{-1}$  for *P. pessuliferus* from DBNP and Suakin

respectively, while the values for *P. areolatus* from DBNP and Suakin were equaled  $1.1602 \text{ yr}^{-1}$  and  $1.0476 \text{ yr}^{-1}$ . Natural mortality rate (M) was obtained at values of  $0.235 \text{ yr}^{-1}$  and  $0.215 \text{ yr}^{-1}$  for *P. pessuliferus* from DBNP and Suakin respectively, while the values for *P. areolatus* from DBNP and Suakin equaled  $0.295 \text{ yr}^{-1}$  and  $0.344 \text{ yr}^{-1}$ .

Consequently, the fishing mortality rates (F) were calculated with the values of  $0.511 \text{ yr}^{-1}$  and  $0.531 \text{ yr}^{-1}$  for *P. pessuliferus* from DBNP and Suakin respectively, while the values for *P. areolatus* from DBNP and Suakin were equaled  $0.865 \text{ yr}^{-1}$  and  $0.703 \text{ yr}^{-1}$ . In addition, the exploitation rate (E) was determined with the values of 0.685 and 0.712 for *P. pessuliferus*; 0.746 and 0.671 for *P. areolatus*, from DBNP and Suakin respectively. All values of exploitation rate for two species in two areas exceeded 0.5 which considered as optimum exploitation rate for any fish stock.

Meanwhile, length at first capture ( $L_c$ ) was determined with the values of 46.94 and 47.12cm for *P. pessuliferus*; 34.19 and 32.46cm for *P. areolatus*, from DBNP and Suakin respectively. From the analyses of yield-per-recruit (Y/R) and biomass-per-recruit (B/R), found that  $F_{\max}$  obtained with values of 0.421 and 0.350 for *P. pessuliferus*; 0.498 and 0.690 for *P. areolatus*, from DBNP and Suakin respectively. All values of present or actual fishing mortalities for two species from DBNP and

Suakin exceeded the optimum fishing rate ( $F_{0.1}$ ) and even exceeded the  $F_{max}$ . However, the length at first capture was lower than the length at first maturation for both species in two areas. This finding shows that the fish stock suffers from growth overfishing. More than the high catch of these species in spawning –aggregation- time. It is therefore recommended that to apply suitable management methods such as closing season, closing area, or minimum size, which must be higher than the  $L_m$  of *P. pessuliferus* and *P. areolatus*.

Landing for two species declined sharply by percentage 50-60% from what recorded in 1999. This declination may be happened directly after the year 2003 due to missing data for years 2004 and 2005. The fluctuation of percentages for these of two species different totally before and after the year 2003, e.g. from years 1999-2003 the range is from 14.4-20.4%, and from the years 2006-2010 the range is from 4.9 - 8.1%. From the data obtained from trader's records the highest catch of fishes observed in June (summer) and the lowest catches in appeared in January (winter). High quantities of *P. pessuliferus* and *P. areolatus* in June and lowest quantities in December. Urgent management must apply to protect *P. pessuliferus* and *P. areolatus* in Sudanese Red Sea coast.

Abstrak ini dikemukakan kepada Senat Universiti Malaysia Terengganu untuk memenuhi keperluan untuk ijazah Doktor Falsafah.

**PENILAIAN SUMBER DAN DINAMIK POPULASI IKAN  
*Plectropomus pessuliferus* DAN *Plectropomus areolatus* DI  
PERAIRAN PANTAI LAUT MERAH SUDAN**

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Ikan kerapu terumbu karang, *Plectropomus pessuliferus* dan *Plectropomus areolatus* yang masing-masing dikenali sebagai "Najil" dan "Silimani" oleh orang-orang tempatan adalah merupakan ikan pilihan utama kepada nelayan-nelayan kecil di perairan Laut Merah Sudan untuk selama dua dekad yang lampau. Kedua-dua spesis ini merupakan ikan yang mempunyai hayat hidup yang panjang dengan kadar tumbesaran yang perlahan dan kadar kematian semulajadi yang rendah. Kedua-dua spesis ini adalah dari jenis protogeni, mempunyai kecenderungan untuk berkumpul di satu tempat tertentu semasa musim bertelur yang dengan ini boleh mengakibatkan mereka terdedah kepada kematian tangkapan yang lebih tinggi.

Walau bagaimanapun, tidak banyak maklumat yang telah dikaji berhubung dengan biologi populasi bagi kedua-dua spesies ini di perairan Sudan yang dengannya boleh membantu menguruskan sumber kearah eksploitasi mapan. Bagi memenuhi permintaan ini, satu kajian mengenai beberapa aspek biologi dan dinamik populasi ikan *P. pessuliferus* dan *P. areolatus* yang terdapat di dua perairan pantai Laut Merah Sudan iaitu Taman Laut Tasik Dunganob dan Kepulauan Mukkawar (DBNP) di utara dan Suakin di Selatan telah dilaksanakan bermula dari Ogos 2009 hingga September 2010.

Bilangan spesimen mengikut spesies dan kawasan yang telah dicerap untuk tujuan kajian ini adalah seperti berikut; (a) sebanyak 213 spesimen *P. pessuliferus* dari perairan DBNP, (b) sebanyak 165 spesimen *P. pessuliferus* dari perairan Suakin, (c) sebanyak 272 *P. areolatus* dari perairan DBNP, dan (d) 262 spesimen *P. areolatus* dari perairan Suakin. Julat saiz bagi spesimen *P. pessuliferus* adalah antara 300 – 900 mm manakala bagi specimen *P. areolatus* julatnya adalah antara 245 – 775 mm. Pengambilan sampel dilakukan secara bulanan bagi menentukan ciri-ciri reproduktif biologi, menganggar parameter-parameter tumbesaran, kadar kematian dan hasil-per-rekrut dan biojisim-per-rekrut. Sebagai tambahan, satu program kaji selidik perikanan di kedua-dua lokasi telah dijalankan bagi menentukan hasil tangkapan dan tangkapan per unit usaha (CPUE). Disamping itu, data-

data dari Jabatan Perikanan dan rekod-rekod tangkapan dari pemborong ikan juga digunakan bagi menentukan status perikanan bagi kedua-dua spesis di bawah kajian. Didapati min CPUE bagi perairan Suakin ialah 2.04 kg per jam dan 1.20 kg per nelayan dan CPUE bagi perairan DBNP ialah 4.08 kg per jam dan 2.49 kg per nelayan. Analisis menunjukkan min CPUE bagi *P. areolatus* adalah lebih tinggi berbanding dengan *P. pessuliferus* bagi kedua-dua perairan. Keseluruhannya, nisbah seks antara betina dengan jantan menunjukkan bahawa spesis-spesis ini mempunyai perbezaan yang nyata dari 1:1. Terdapat bukti histologi yang jelas menunjukkan bahawa perubahan seks dari betina kepada jantan berlaku bagi kedua-dua spesis *P. pessuliferus* dan *P. areolatus*. Berasaskan kepada data-data taburan bermusim peringkat kematangan, graf turun-naik indeks gonadosomatik(GSI), keputusan daripada hasil tinjauan soalselidik, statistic pendaratan ikan dan rekod-rekod pendaratan dari pemborong ikan dapat disimpulkan bahawa musim bertelur bagi *P. pessuliferus* di perairan DBNP berlaku dari Mac hingga Julai manakala di perairan Suakin bermula dari Mac hingga Mei. Musim bertelur bagi *P. areolatus* di perairan DBNP berlaku dari Mei hingga Julai dan perairan Suakin diantara April hingga Jun.

Panjang-pada-mula matang ( $L_m$ ) bagi *P. pessuliferus* mengikut sex di perairan masing-masing adalah seperti berikut; (a) ikan betina di

perairan DBNP ialah 57.2 sm, (b) ikan jantan di perairan DBNP ialah 61.4 sm, (c) ikan betina di perairan Suakin ialah 57.4 sm, dan (d) ikan jantan di perairan Suakin ialah 64.5 sm. Panjang-pada-mula matang ( $L_m$ ) bagi *P. areolatus* mengikut sex di perairan masing-masing adalah seperti berikut; (a) ikan betina di perairan DBNP ialah 45.3 sm, (b) ikan jantan di perairan DBNP ialah 47.4 sm, (c) ikan betina di perairan Suakin ialah 42 sm, dan (d) ikan jantan di perairan Suakin ialah 43.3 sm. Ukuran panjang-pada-mula matang di ukur berasaskan kepada  $L_{50}$  iaitu ukuran apabila 50% daripada populasi mencapai matang dan ukuran L adalah dalam unit panjang keseluruhan (Total length -TL).

Panjang-pertukaran-seks ( $L_s$ ) dari betina kepada jantan untuk *P. pessuliferus* bagi populasi ikan di perairan DBNP ialah 67.9 sm dan 74.9 sm bagi populasi ikan di perairan Suakin.  $L_s$  untuk *P. areolatus* dari perairan DBNP adalah 50.3 sm dan di perairan Suakin  $L_s$  adalah 47.1 sm. Fekunditi sebenar untuk populasi *P. pessuliferus* di perairan DBNP adalah berjulat antara 584,017 hingga 8,069,392 telur dengan purata sebanyak 2,258,873 telur per betina matang manakala untuk populasi *P. pessuliferus* di perairan Suakin adalah berjulat antara 577,334 hingga 3,364,966 telur dengan purata 1,312,581 telur per betina matang. Populasi *P. areolatus* di perairan DBNP menunjukkan bahawa fekunditi sebenar ikan ini adalah 586,763 hingga 4,057,030 telur dengan purata 1,596,282 telur per betina matang.

Tulang vertebra dan otolit sagital telah digunakan bagi menentukan struktur umur bagi stok ikan. Struktur tulang otolit bagi ikan ini adalah berbentuk cembung dan elip; pada bahagian permukaan cekung tulang ini didapati ia menghala ke arah paksi tengah ikan. Terdapat tanda bulatan tahunan yang jelas pada kedua-dua tulang samada vertebra dan otolit dimana zon legap yang mempunyai lapisan yang lebih gelap sebagai bulatan tahunan dapat dipisah dengan zon cerah atau lutsinar bersebelahan dengannya. Terdapat sepuluh kumpulan-umur bagi populasi *P. pessuliferus* di perairan DBNP dan sebelas kumpulan-umur di perairan Suakin. Manakala lapan kumpulan-umur bagi populasi *P. areolatus* di perairan DBNP dan enam kumpulan-umur populasi *P. areolatus* di perairan Suakin.

Parameter-parameter tumbesaran bagi Persamaan Tumbesaran Von Bertalanffy (VBGF) untuk *P. pessuliferus* dan *P. areolatus* di setiap lokasi kajian adalah sebagaimana yang diberikan di bawah ini;

- (1) *P. pessuliferus* di DBNP;  $L_t = 116.836 [1 - e^{(-0.120 [t - (-2.45)])}]$
- (2) *P. pessuliferus* di Suakin;  $L_t = 122.194 [1 - e^{(-0.112 [t - (-2.59)])}]$
- (3) *P. areolatus* di DBNP;  $L_t = 88.725 [1 - e^{(-0.143 [t - (-2.49)])}]$
- (4) *P. areolatus* di Suakin;  $L_t = 79.273 [1 - e^{(-0.163 [t - (-2.55)])}]$

Anggaran jumlah kematian bagi telah dianalisis menggunakan kaedah keluk tangkapan. Keputusan menunjukkan bahawa jumlah kematian

bagi populasi *P. pessuliferus* adalah hampir sama bagi kedua-dua perairan, iaitu perairan DBNP dengan nilai 0.7460 per tahun manakala perairan Suakin nilainya adalah 0.7466 per tahun. Sekiranya, perbandingan dilakukan diantara spesies keputusan menunjukkan bahawa *P. areolatus* mempunyai nilai jumlah kematian yang lebih tinggi berbanding dengan *P. pessuliferus*. Kajian menunjukkan bahawa populasi *P. areolatus* di perairan DBNP mempunyai nilai jumlah kematian yang lebih tinggi sedikit berbanding dengan perairan Suakin iaitu masing-masing dengan nilai 1.1602 per tahun dan 1.0476 per tahun. Kadar kematian semulajadi (M) bagi populasi *P. pessuliferus* di perairan DBNP adalah 0.235 per tahun dan 0.215 per tahun bagi perairan Suakin. Nilai kadar kematian semulajadi bagi *P. areolatus* di perairan DBNP adalah 0.295 per tahun dan di perairan Suakin adalah 0.344 per tahun.

Kadar kematian tangkapan (F) bagi populasi *P. pessuliferus* di perairan DBNP adalah 0.511 per tahun manakala di perairan Suakin adalah 0.531 per tahun. Kadar kematian tangkapan (F) bagi populasi *P. areolatus* di kedua-dua perairan adalah lebih tinggi berbanding populasi *P. pessuliferus*. Di perairan DBNP nilai kadar kematian tangkapan bagi populasi *P. areolatus* adalah 0.865 per tahun manakala di perairan Suakin 0.703 per tahun. Kadar eksploitasi (E) yang bagi populasi *P. pessuliferus* dianggarkan bernilai 0.685 di perairan DBNP dan 0.712 di

perairan Suakin. Manakala, kadar eksploitasi bagi populasi *P. areolatus* di perairan DBNP adalah 0.746 dan 0.671 di perairan Suakin. Kadar eksploitasi di kedua-dua perairan didapati melebihi nilai 0.5 iaitu nilai yang dianggap sebagai kadar eksploitasi yang optimum bagi mana-mana sumber perikanan.

Panjang-mula-ditangkap ( $L_c$ ) bagi perikanan *P. pessuliferus* di perairan DBNP adalah 46.94 sm dan 47.12 di perairan Suakin. Manakala, *P. areolatus* di perairan DBNP adalah 34.19 sm dan 32.46 sm di perairan Suakin. Analisa menunjukkan bahawa hasi-per-rekrut ( $Y/R$ ) dan biojisim-per-rekrut ( $B/R$ ) pada tahap  $F_{max}$  bagi (a) *P. pessuliferus* diperairan DBNP adalah 0.421, (b) *P. pessuliferus* di perairan Suakin adalah 0.350, (c) *P. areolatus* di perairan DBNP adalah 0.498 dan (d) *P. areolatus* bagi perairan Suakin adalah 0.690. Nilai kematian tangkapan semasa bagi kedua-dua spesis di kedua-dua perairan sebenarnya telah melebihi kadar kematian optima ( $F_{0.1}$ ) malah  $F_{max}$ . Walau bagaimanapun, panjang-pada-mula tangkap adalah lebih rendah daripada panjang-pada-mula matang untuk kedua-dua spesis di kedua-dua perairan. Kajian ini mendapati bahawa stok ikan bagi perikanan *P. pessuliferus* dan *P. areolatus* mengalami kemusnahan berpunca daripada penangkapan ikan kecil berlebihan yang menyebabkan ia tidak sempat membesar. dimana tangapan paling tinggi didapati berlaku semasa musim bertelur atau berkumpul. Oleh yang

demikian, antara langkah-langkah pengurusan yang dicadangkan bagi melindungi perikanan ini adalah dengan menutup tangkapan pada musim dan kawasan tertentu atau mengamalkan pengurusan batasan saiz ikan ditangkap yang saiz yang ditetapkan sepatutnya melebihi dari  $L_m$  mengikut spesis masing-masing.

Pendaratan bagi kedua-dua spesis menunjukkan corak penurunan yang sangat ketara yang secara keseluruhannya 50- 60% daripada yang direkodkan berbanding 1999. Kemerosotan pendaratan ini didapati berlaku selepas 2003 yang mungkin berpunca daripada kehilangan data 2004 dan 2005. Turun naik jumlah pendaratan ikan bagi kedua-dua spesis adalah jauh berbeza diantara sebelum dan selepas 2003 dimana dari tahun 1999 hingga 2003 julatnya antara 14.4 hingga 20.4% dan dari tahun 2006 hingga 2010 julatnya antara 4.9 – 8.1%. Data daripada pemborong menunjukkan bahawa jumlah hasil tangkapan untuk semua spesis didapati paling tinggi berlaku pada bulan Jun (musim panas) dan tangkapan paling rendah berlaku pada bulan Januari (musim sejuk). Dari segi kuantiti pendaratan paling banyak bagi dua spesis iaitu *P. pessuliferus* dan *P. areolatus* berlaku dalam bulan Jun dan paling rendah dalam bulan Disember. Kesimpulannya, langkah-langkah pengurusan yang segera perlu di ambil tindakan bagi

melindungi sumber perikanan *P. pessuliferus* dan *P. areolatus* di perairan pantai Laut Merah Sudan dari kemerosotan.

I am very grateful to my supervisor, Prof. Dr. H. M. M. Abd. Aziz, for his guidance and support throughout the study. I would like to extend my sincere thanks to Prof. Dr. H. M. M. Abd. Aziz, the Director of the supervisory committee, for his valuable contribution, advice, criticism, and supervision of my study, and providing research facilities and facilities for my study. I would like to thank my study advisor, Prof. Dr. H. M. M. Abd. Aziz, for his valuable contribution, advice, criticism, and supervision of my study. I would like to thank my study advisor, Prof. Dr. H. M. M. Abd. Aziz, for his valuable contribution, advice, criticism, and supervision of my study. I would like to thank my study advisor, Prof. Dr. H. M. M. Abd. Aziz, for his valuable contribution, advice, criticism, and supervision of my study.

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