Wissenschaftlich-technische Zusammenarbeit mit Indonesien

BMBF-Programm SPICE II

Science for the Protection of Indonesian Coastal Ecosystems

BMBF-Verbundprojekt

SYSMAR

Integriertes System für das Management einer ökologisch und sozio-ökonomisch nachhaltigen Marikultur in Indonesien

Teilprojekt 1

FKZ 03F0469A

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ABSCHLUSSBERICHT

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SPICE

A German-Indonesian Initiative in Earth System Research

Allgemeiner Überblick

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Projekttitel

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Projektlaufzeit

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Abkürzungen

CORELAB	Coastal Research Laboratory (Küstengeologie/Küsteningenieurswissenschaften) im Forschungs- und Technologiezentrum Westküste der Universität Kiel
DAAD	Deutscher Akademischer Austauschdienst
DKP	Departemen Kelautan Dan Perikanan (Ministerium für Marine Angelegenheiten und Fischerei / Indonesien)
DSS	Decision Support System
DUAG	Deutsche Umwelt AG
FCR	Feed Conversion Ratio
FTZ	Forschungs- und Technologiezentrum Westküste der Universität Kiel
GEBCO	General Bathymetric Card of the Oceans
GIS	Geographisches Informationssystem
GRIM	Gondol Research Institute for Mariculture, Bali, Indonesia
GUI	Graphical User Interface
IfW	Institut für Weltwirtschaft an der Universität Kiel
IPB	Institut Pertanian Bogor (Bogor Agricultural Institute)
ITB	Institut Teknologi Bandung (Bandung Institute of Technology)
NCEP	National Centers for Environmental Prediction
POC	Particulate Organic Carbon
RSH	Recirculation System Hatchery
SPICE	Science for the Protection of Indonesian Coastal Ecosystems
SYSMAR	System for the Management of Mariculture
TDN	Total Dissolved Nitrogen
TPXO	TOPEX/POSEIDON Global Tidal Model
WTZ	Wissenschaftlich-technische Zusammenarbeit
ZMT	Zentrum für Marine Tropenökologie, Bremen

Contents

I. Allgemeiner Teil

1. Vorbemerkung

Das Verbundvorhaben zur Entwicklung eines integrierten Systems für das Management einer ökologisch und sozio-ökonomisch nachhaltigen Marikultur in Indonesien (SYSMAR) ist Teil der bilateralen wissenschaftlich-technischen Zusammenarbeit der deutschen Bundesregierung mit Indonesien, welche ihre entwicklungspolitische Grundlage in dem bereits 1979 geschlossenen WTZ-Abkommen beider Länder hat. Das in 2003 initiierte SPICE-Programm (Science for the Protection of Indonesian Coastal Ecosystems) ist dem Themenbereich Meeresforschung und Geowissenschaften zugeordnet und verfolgt als übergreifendes Ziel eine nachhaltigere Ressourcennutzung der stark gefährdeten indonesischen Küstenökosysteme zu bewirken. Die indonesischen Küstenzonen sind einer Vielzahl unterschiedlicher Belastungen ausgesetzt, deren negative Auswirkungen sich besonders deutlich in küstennahen Ballungsgebieten, wie der Metropolregion Jakarta, äußern. Der fortschreitende Raubbau an den Küstenressourcen durch Nutzungskonversion, wie Urbanisierung, Forstwirtschaft, Aquakultur und Tourismus, die Einleitung großer Mengen ungeklärter kommunaler und industrieller Abwässer, destruktive Fischereipraktiken wie Dynamit- und Zyanidfischerei sowie Überfischung der heimischen Bestände führen zu einem besorgniserregenden Verlust natürlicher Lebensräume und der Artenvielfalt indonesischer Küstenökosysteme.

Rund 60% des Proteinbedarfs der indonesischen Bevölkerung wird aus Fischerei und Aquakultur gedeckt. Allein die Riff-Fischerei hat hieran einen Anteil von 22%. Die Fischereierträge Indonesiens haben sich mit ca. 5 Millionen Tonnen in 2010 in den letzten 4 Jahrzehnten vervierfacht. Eine weitere Steigerung ist jedoch kaum zu erwarten. Der Großteil der Fänge dient der Deckung des Eigenbedarfs. Ein wichtiges entwicklungspolitisches Ziel der indonesischen Regierung ist daher der weitere Ausbau der Fischzucht, die insbesondere kleinen Familienunternehmen eine Einkommensquelle sichern soll. Aquakulturprodukte aus Marikultur, Süß- und Brackwasserzucht (einschl. Großalgen, Garnelen und Mollusken) erreichten bereits in 2010 eine Jahresproduktion von 6 Millionen Tonnen. Marine Speisefische werden in Indonesien vorwiegend in küstennahen Käfiganlagen gezüchtet, die Hauptfischarten sind hochpreisige Riffbarsche, die vorwiegend exportiert werden, aber auch Milchfisch (*Chanos chanos*), der in erster Linie der heimischen Versorgung dient.

Angesichts der Entwicklungsziele der indonesischen Behörden in der Aquakultur, die für 2011 ein Produktionsziel von knapp 7 Millionen Tonnen und bis 2014 eine Steigerung auf 16,9 Millionen Tonnen Gesamtproduktion vorsehen, werden Planungswerkzeuge benötigt, die Voraussagen sowohl zur ökologischen als auch zur sozioökonomischen Nachhaltigkeit zukünftiger Fischzuchtaktivitäten in den indonesischen Küstenzonen liefern können. Diesem Bedarf wurde mit der Zielstellung des vorliegenden Verbundvorhabens entsprochen.

2. Aufgabenstellung

In enger Zusammenarbeit mit dem Research Center for Aquaculture des DKP (Ministry of Marine Affairs and Fisheries) in Jakarta und dem Gondol Research Institute for Mariculture auf Bali (GRIM) sollte ein integriertes Decision Support System (DSS) für einen nachhaltigen Ausbau der Fischzuchtaktivitäten in indonesischen Küstengewässern entwickelt werden, in dem sowohl umweltrelevante als auch sozioökonomische Entscheidungskriterien zusammengeführt werden, um eine in beiderlei Hinsicht ausgewogene Entwicklung der Fischzucht zu gewährleisten. Der Schwerpunkt lag hierbei auf der in Indonesien üblichen Käfigfischzucht insbesondere von Zackenbarschen („Grouper"). Das System stützt sich auf eine Kombination von Felddaten, numerischer Modellierung und GIS-Datenbanken. Es gestattet eine optimierte Auswahl von Eignungsgebieten zur Ansiedlung von Fischfarmbetrieben und ermöglicht darüber hinaus eine gebietsspezifische Abschätzung der ökologischen Tragfähigkeit (Teilprojekt 1) sowie der Wirtschaftlichkeit (Teilprojekt 2) verschiedener Ausbauszenarien.

Das Vorhaben knüpft damit an die in der ersten Phase des SPICE-Programms/Cluster 3.2 durchgeführten Forschungsarbeiten an, welche die konzeptionelle Entwicklung der DSS-Module zur Selektion von Eignungsgebieten für Fischzuchtanlagen zum Ziel hatten. Es liefert als Endprodukt ein modernes Werkzeug für Regierungsstellen und Fachagenturen, die in Entscheidungsprozesse der Küstenraumplanung einbezogen sind. Die praktische Anwendung des Systems erfolgte auf zwei Gebiete auf Bali und Sumbawa, die im Rahmen des Entwicklungsplans des DKP für einen zukünftigen Ausbau der Fischzucht vorgesehen sind.

Eng verknüpft mit den Forschungsaktivitäten erfolgte eine Intensivierung des Capacity Building durch Trainingskurse in Indonesien und Ausbildung im Postgraduierten- und Doktorandenprogramm „Coastal Geosciences and Engineering" an der Universität Kiel.

Abb. 1: Käfigfischzucht in Pegametan Bay, Nord Bali

3. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das Vorhaben war dem Cluster 3 des SPICE-Programms/Phase II zugeordnet und wurde im Verbund mit dem Forschungs- und Technologiezentrum Westküste (FTZ) der Universität Kiel, dem Institut für Weltwirtschaft (IfW) an der Universität Kiel, der Deutschen Umwelt AG (duag) in Kiel, dem Gondol Research Institute for Mariculture (GRIM), Bali, dem Central Research Center for Aquaculture des DKP, Jakarta, sowie dem Bandung Institute of Technology (ITB) durchgeführt. Es ist in zwei Teilprojekte untergliedert, welche jeweils die ökologische Tragfähigkeit (TP 1, FTZ Westküste) und die wirtschaftliche Nachhaltigkeit (TP 2, IfW Kiel) behandeln. Im vorliegenden Abschlussbericht werden die im Teilprojekt 1 des Gesamtvorhabens erzielten Ergebnisse vorgestellt.

Das Projekt wurde vom BMBF für eine Gesamtlaufzeit von 40 Monaten gefördert. Federführend war auf deutscher Seite das FTZ Westküste (Prof. Dr. R. Mayerle), auf indonesischer Seite das GRIM (Dr. A. Hanafi). Leider verstarb unser geschätzter Partner, Herr Dr. Hanafi, überrraschend am 11. September 2010. Die Nachfolge als Projektkoordinator am GRIM übernahm Herr Dr. Adiasmara Giri. Die Koordination des SPICE-Gesamtverbundes oblag dem Zentrum für Marine Tropenökologie (ZMT) in Bremen (Prof. Dr. V. Ittekkot). Der Projektträger Jülich, Bereich MGS in Rostock-Warnemünde, war mit der Abwicklung der Fördermaßnahme betraut. Ihm sei an dieser Stelle für die sachkundige und konstruktive Projektbetreuung gedankt.

Als besonders förderlich für die Durchführung des Projektes erwiesen sich die einschlägige Auslandserfahrung des Projektteams und die zahlreichen Kontakte zu indonesischen Behörden und Fachinstitutionen, die während der ersten Projektphase (SPICE I) geknüpft werden konnten. Die Zusammenarbeit mit dem indonesischen Partner GRIM, Herrn Dr. Adi Hanafi, verlief problemlos und war durchweg erfolgreich. Insbesondere bezüglich der logistischen Erfordernisse zur Durchführung der Feldmesskampagnen wurde seitens des Partners stets wertvolle Unterstützung geleistet, ohne die der reibungslose Ablauf der Forschungsaktivitäten erheblich erschwert worden wäre. Dies betraf auch die Abwicklung der Zollformalitäten für den Gerätetransport. Die Messeinsätze wurden gemeinschaftlich geplant und umgesetzt, Laborkapazitäten standen am GRIM im ausreichenden Umfang zur Verfügung. Zwischen den Messkampagnen erfolgten eigenständige Untersuchungen der indonesischen Kollegen zur Nährstoffdynamik des Testgebietes Pegametan/Bali im Rahmen eines Monitoring. Methodik und Qualitätssicherung der Messungen erfolgten nach internationalem Standard (Grasshoff et al. 2002) und Doppelbeprobungen. GRIM stellte darüber hinaus Datensätze zu Produktion, Besatz und Betrieb der Fischzuchtanlagen zur Verfügung, betreute die operationellen Pegellogger und die meteorologische Station, die bereits zu Beginn des Vorhabens auf dem dortigen Institutsgelände installiert und dem Partner übereignet wurde. Das Central Research Institute for Aquaculture des DKP in Jakarta (Dr. K. Sugama) lieferte u.a. Informationen zu den wirtschaftspolitischen Planungszielen für die indonesische Marikulturentwicklung, dem Marktbedarf und der gesetzlichen Regelungswerke. Gemeinsame Präsentationen der Projektergebnisse fanden u.a. anlässlich der World Ocean Conference 2009 in Manado statt.

Nicht zuletzt wegen der guten Kontakte zu indonesischen Wissenschaftlern, die in den vergangenen Jahren mit Unterstützung des DAAD im FTZ Westküste/CORELAB ausgebildet worden sind, hat sich auch die Kooperation mit dem assoziierten universitären Projektbeteiligten ITB Bandung und dem IPB Bogor sehr positiv weiterentwickelt. Die hierdurch gewonnene Unterstützung der indonesischen Alumnis hat wesentlich zur erfolgreichen Durchführung von SYSMAR beigetragen.

Während der Projektlaufzeit wurden regelmäßige Arbeitstreffen der deutschen Projektpartner in Kiel durchgeführt. Bilaterale Veranstaltungen mit den indonesischen Partnern und Behördenvertretern fanden mehrfach sowohl in Deutschland als auch in Indonesien statt. Der indonesische Koordinator des SPICE-Clusters 3, Herr Dr. Ketut Sugama, übernahm im Herbst 2008 die Leitung des Institute for Seed Production des DKP. Sein Nachfolger am Central Institute for Aquaculture, Herr Dr. Enday Kusnendar, übernahm daraufhin die Koordination des Clusters 3 und fungierte für die restliche Zeit daher auch als indonesischer Ansprechpartner für das vorliegende Verbundprojekt. Die folgende Tabelle gibt eine Übersicht über die wichtigsten Projektaktivitäten.

Tab. 1: Chronologische Übersicht der Aktivitäten

Chronologie	Aktivität
11.04. - 03.05.2008	1. Intensivmesskampagne Pegametan Bay, Bali
Juni 2008	Besuch indonesische DKP-Delegation in Kiel (Dr. Maruf et al.)
August 2008	Informationsbesuch indonesischer Generalkonsul (Teuku Darmawan), Kiel
10.11. - 11.11.2008	Präsentation von Projektergebnissen, Dr. K. Sugama, SPICE-Round Table, Pekanbaru, Sumatra
01.12. - 18.12.2008	2. Intensivmesskampagne Pegametan Bay/Bali und Saleh Bay/Sumbawa
15.12.2008	Bilaterales Koordinationstreffen, Institute of Seed Production, DKP Jakarta
21.04. - 22.04.2009	Präsentation von Projektergebnissen, International Symposium Scottish Aquaculture, Edinburgh
11.05. - 15.05.2009	Präsentation von Projektergebnissen, Steering Committee-Sitzung, World Ocean Conference, Manado
04.06. - 18.06.2009	3. Intensivmesskampagne Pegametan Bay, Bali und Saleh Bay, Sumbawa
06.10. - 23.10.2009	Intensivtraining Dr. Hanafi, MSc. Johan am CORELAB/FTZ Westküste
30.11. - 12.12.2009	4. Intensivmesskampagne Pegametan Bay und Celukan Bawang, Bali
09.12.2009	Präsentation zukünftiger Projektaktivitäten, Dr. C. Schultz, SPICE II Meeting, ZMT, Bremen
10.12. - 14.12.2009	Trainingskurse zum DSS am GRIM, Gondol und Seacorm, Negara
20.04. - 21.04.2010	Projektpräsentation Dr. K. Sugama, Dr. A. Hanafi, SPICE-Evaluation Seminar, RISTEK, Jakarta
10.05. - 17.05.2010	Koordinationsreise DKP Jakarta, IPB Bogor, ITB Bandung, GRIM Gondol
13.06. - 17.06.2010	Projektpräsentation, S. A. van der Wulp, XVIIth World Congress of the International Commission of Agricultural Engineering (CIGR), Quebec, Canada.
26.10. - 29.10.2010	SPICE Zukunfts-Workshop, ZMT, Bremen
09.12. - 22.12.2010	Koordinationsreise DKP, BPPT Jakarta, IPB Bogor

4. Planung und Ablauf des Vorhabens

Die Planung des Vorhabens erfolgte in enger Abstimmung mit den indonesischen Projektpartnern Dr. Adi Hanafi (GRIM), Dr. Adiasmara Giri (GRIM) und Dr. Ketut Sugama (DKP). Der in das DSS implementierte Entscheidungsprozess (Abb. 2) sieht im Einzelnen folgende Schritte vor:

- Vorauswahl von Küstengebieten zur DSS-Anwendung. Sie erfolgt auf politischer Ebene
- Identifizierung und Gewichtung von Kriterien zur Umweltnachhaltigkeit (TP 1)
- Akquisition erforderlicher Daten und Überführung in die GIS-Datenbank des DSS (TP 1)
- Auswahl von Eignungsgebieten auf regionaler Ebene (Screening) (TP 1)
- Feinauswahl prioritärer Eignungsgebieten auf lokaler Ebene (TP 1)
- Bestimmung der zulässigen Größe und Produktionskapazität zukünftiger Fischzuchtanlagen auf Grundlage von Umweltbelastungsgrenzen stofflicher Emissionen und Immissionen (TP 1)
- Identifizierung sozioökonomischer Erfordernisse zur Einrichtung und Betrieb der Anlagen (TP 2)
- Bestimmung der Wirtschaftlichkeit bei verschiedenen Produktionsszenarios (TP 2)
- Synthese des Entscheidungsprozesses durch Integration der ökologischen und sozioökonomischen Produktionsgrenzwerte (TP 1 und TP 2)

Zur Weiterentwicklung des DSS wurden folgende Arbeiten durchgeführt: Das in der ersten Projektphase (SPICE I) entwickelte DSS-Modul zur Bewertung der ökologischen Nachhaltigkeit der Fischzuchtaktivitäten wurde im Rahmen des vorliegenden Projektes verfeinert und erweitert. Dies betraf vor allem die Einbeziehung der partikulären Emissionen aus den Farmbetrieben, die entsprechenden Depositionsraten partikulärem Materials, die Sedimentqualität, die Definition von Grenzwerten der organischen Sedimentbelastung sowie die Berücksichtigung von Vorbelastungen durch Nährstoffeinträge aus weiteren anthropogenen Quellen, insbesondere flussbürtiger Einträge.

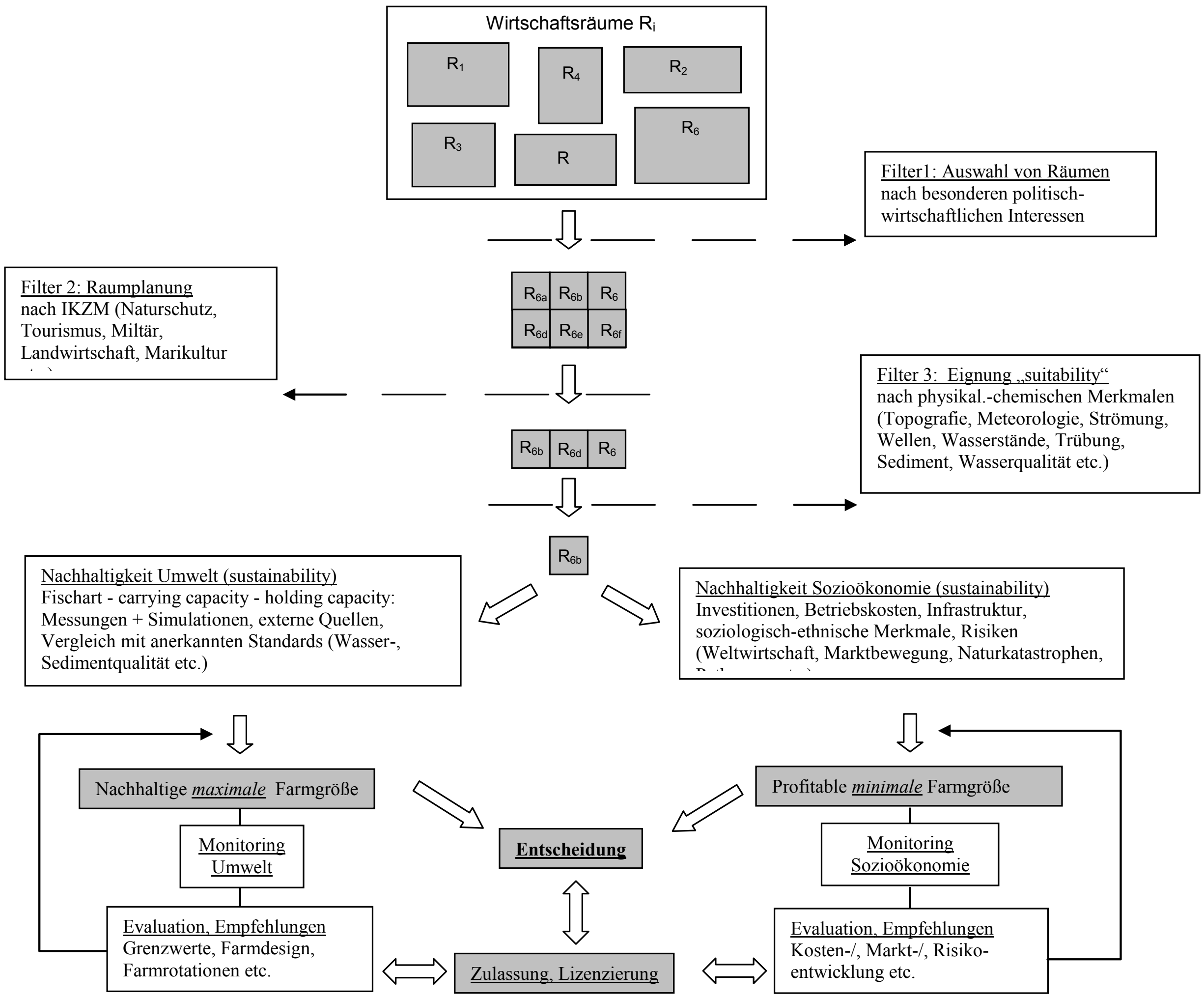


Abb. 2: Entscheidungskaskade im DSS

Als Untersuchungsgebiet hierfür wurde das Experimentalfeld Pegametan Bay auf Bali ausgewählt (Abb. 3), da es sich in der Nähe des Gondol Research Institute for Mariculture (GRIM) befindet und für die dort angesiedelten Fischzuchtbetriebe ausreichend Daten zur Verfügung stehen. Eine partielle Validierung des DSS für Umweltnachhaltigkeit erfolgte für die Deposition partikulären organischen Materials an zwei Fischfarmen in Pegametan Bay mit guten Ergebnissen.

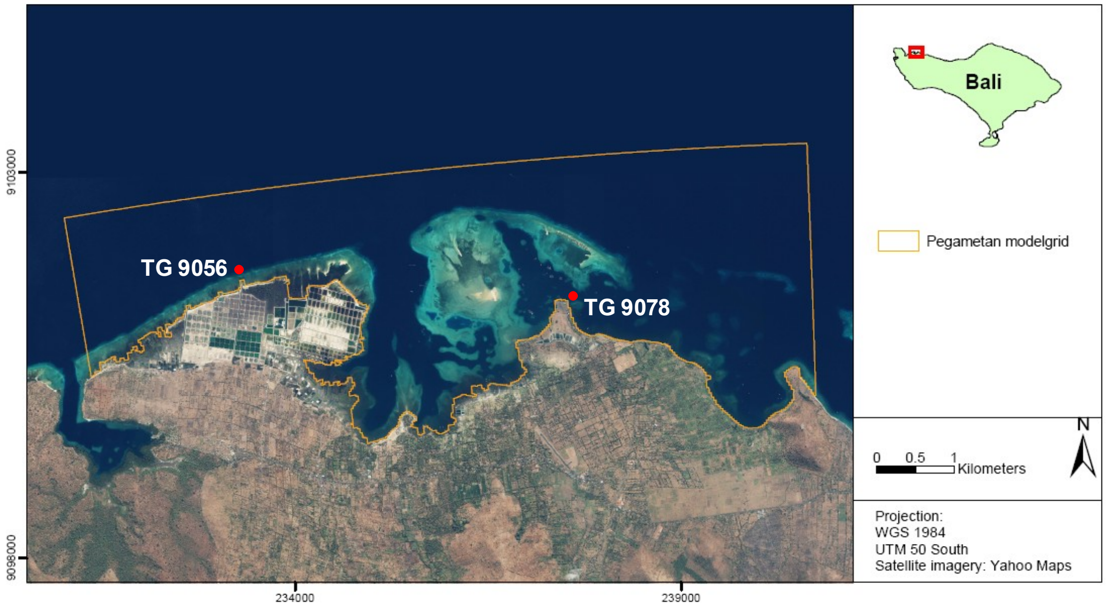


Abb. 3: Modellgebiet Pegametan Bay, offene Seegrenzen, Position der Pegel

Auf Grundlage einer Analyse der Schlüsseldeterminanten und regionalen Kernkompetenzen der indonesischen Marikultur wurde ein empirisches Modell der Zuchtfischproduktion abgeleitet, welches eine Bewertung künftiger Fischfarmprojekte hinsichtlich ihrer sozio-ökonomischen Durchführbarkeit und Wirtschaftlichkeit gestattet. Zur Erstellung der Indikatoren und zur Formulierung der Produktionsfunktion wurden umfangreiche Datensätze des DKP sowie des Institute of Socio Economics, Jakarta, zur Marikulturstatistik und Marktsituation analysiert und durch eigene Interviews, Betriebsanalysen und Bestandsaufnahmen bestehender Fischzuchtanlagen in Pegametan Bay (Bali) und Saleh Bay (Sumbawa) ergänzt.

Die Setzlingsbeschaffung ist ein wesentlicher Kostenfaktor in der indonesischen Fischmast. Es wurde daher die derzeitige Produktions- und Kostenstruktur der Besatzzucht in Indonesien analysiert und dem gegenwärtigen als auch dem zukünftigen Marktbedarf gegenübergestellt. Ausgehend von der Untersuchung der Prozessabläufe in der traditionellen Setzlingszucht wurden defizitäre Bereiche identifiziert und Optimierungsvorschläge entwickelt. Insbesondere wurde die Möglichkeit zur Implementierung kreislaufgeführter Anlagen für eine weitere Professionalisierung der Produktion von Grouper-Setzlingen untersucht. Der diesbezügliche Stand der Technik wurde recherchiert und die wesentlichen Hemmnisse und Problemstellungen bisheriger Bemühungen zur Einführung tropentauglicher Kreislaufsysteme identifiziert. Als Folge dieser Erkenntnisse wurden Empfehlungen zur

Konzeption einer kreislaufbetriebenen Setzlingsproduktion für Indonesien erarbeitet, um die Grundlage für eine an die landestypischen Bedingungen angepasste Technologieentwicklung zu schaffen.

Begleitend zu den o.g. Aktivitäten wurden die bestehenden Regelwerke für die Zulassung und Lizenzierung von Fischzuchtanlagen in Indonesien sowie die Möglichkeiten ihrer Umsetzung von dem indonesischen Partner GRIM untersucht und dokumentiert. Dabei wurden u.a. auch Regularien berücksichtigt, die international für die Lizenzvergabe und Implementierung von Fischfarmen relevant sind. Hieraus wurden Empfehlungen für eine weitergehende Optimierung von Zulassungsauflagen für indonesische Fischfarmanlagen abgeleitet.

Die zunächst getrennt entwickelten Module für Umweltnachhaltigkeit und Wirtschaftlichkeit wurden mit MatLab in ein benutzerfreundliches Interface integriert. Das Interface ist erweiterbar durch zusätzliche Filter, so dass eine universelle Anwendung auf ein breites Spektrum verschiedener Küsten- und Zuchtbedingungen möglich ist. Als zusätzliches Selektionskriterium kann beispielsweise die hygienische Belastung der Gewässer gelten, was jedoch im vorliegenden System, welches auf Pegametan Bay zugeschnitten ist, von untergeordneter Bedeutung ist.

Eine wesentliche Zielstellung des Vorhabens bestand schließlich in der Demonstration und Anwendung des DSS auf zwei größere Küstengebiete, die a priori im Entwicklungsplan des DKP für eine potentielle Ansiedlung zukünftiger Fischzuchtaktivitäten vorgesehen waren und sich hinsichtlich ihrer Küstencharakteristik unterschieden. Ausgewählt wurde ein offenes Küstengebiet in der östlichen Buleleng Regency an der Nordküste von Bali zwischen Gondol und Singaraja (Abb. 4), sowie die halbabgeschlossene Saleh Bay auf der Insel Sumbawa (Abb. 5). Letztere Region wurde auf Wunsch der indonesischen Partner der ursprünglich für die DSS-Anwendung vorgesehenen Bucht an der Südküste Lomboks vorgezogen.

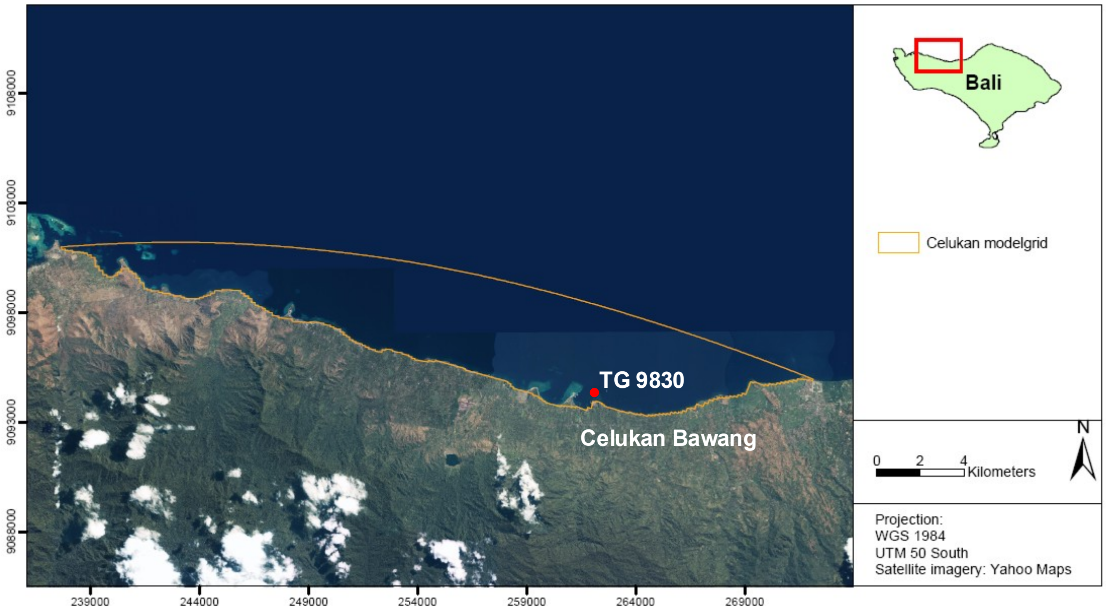


Abb. 4: Modellgebiet Celukan Bawang, Bali, Lage des Pegels

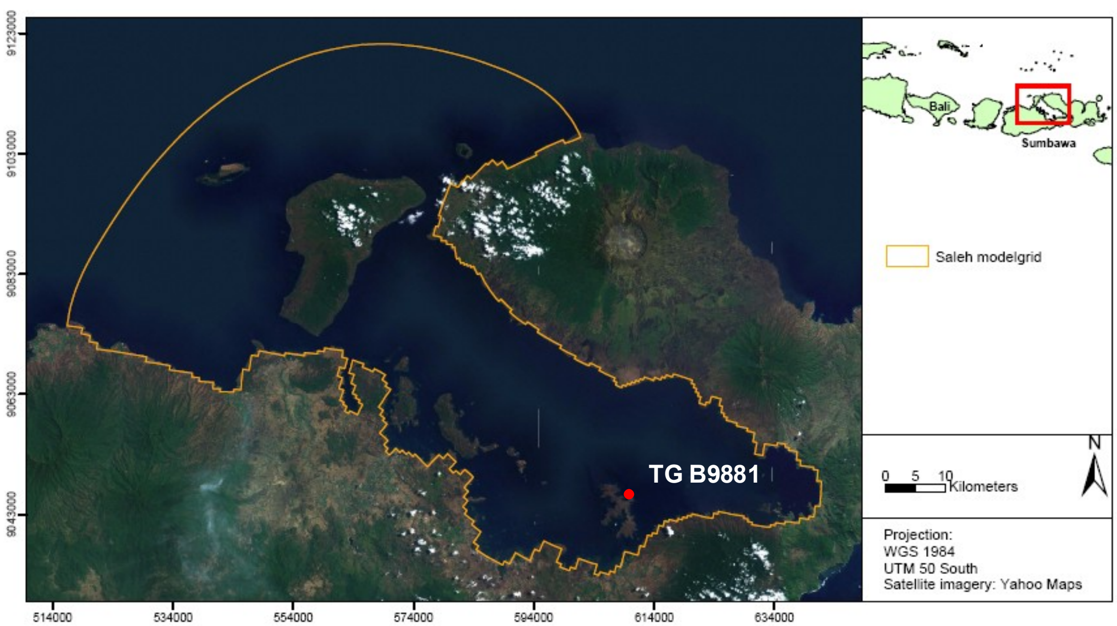


Abb. 5: Modellgebiet Saleh Bay, Sumbawa, Lage des Pegels

4.1. Feldmessungen

Zur Durchführung der Projektarbeiten fanden im April und Dezember 2008 sowie im Juni und Dezember 2009 Intensivmesskampagnen auf Bali und Sumbawa statt. Hierbei wurden umfangreiche Datensätze zur Hydrographie, Hydrodynamik und Wasserqualität erhoben, sowie Messungen zu Nährstoffemissionen und Deposition partikulären organischen Materials im Umfeld der Fischfarmen durchgeführt. Zur kontinuierlichen Erfassung der Wasserstände wurde ein Pegelmessnetz (CeraDiver) durch Taucher aufgebaut. Während der ersten Messkampagne wurde darüber hinaus eine meteorologische Station auf dem Gelände des Gondol Research Center for Mariculture eingerichtet, die kontinuierlich die lokalen Windverhältnisse registrierte. Die Felddaten lieferten u.a. die Grundlage für den Aufbau und Betrieb von numerischen Modellen für Strömung, Seegang und Wasserqualität, welche wiederum die erforderlichen Informationen für die ökologischen DSS-Module bereit stellten.

Im Vorfeld der Untersuchungen wurden Messinstrumente, Beprobungs- und Filtrationsgerätschaften, Chemikalien und weiteres Verbrauchsmaterial nach Bali transportiert. Das Forschungsinstitut GRIM in Gondol stellte Laborkapazitäten, organisierte den Material- und Personentransport und die Schiffe für die Messeinsätze, beteiligte sich an den Messfahrten und Beprobungen, vermittelte die Kontakte zu den Fischfarm-Betreibern und lokalen Behörden und stellte Produktions- und Monitoringdaten zur Verfügung.

4.2. Modellierung

Für alle Untersuchungsgebiete wurden hochauflösende Strömungsmodelle erstellt, die mithilfe der kontinuierlichen Pegelmessungen kalibriert und validiert wurden. Um die Risiken erhöhter Wellenbelastung auf künftige Fischzuchtanlagen zu untersuchen, wurden darüber hinaus Seegangsmodelle aufgesetzt, in denen Szenarien unterschiedlichen Wellengangs verglichen wurden. Für die Modellentwicklung wurde die Delft3D-Software (Delft Hydraulics, The Netherlands) verwendet. Die Ergebnisse der Modellsimulationen bilden eine wichtige Grundlage für die Eignungsanalyse (suitability analysis) des Küstengebietes.

Das Strömungsmodell wurde mit einem Modul für Wasserqualität zur Simulation der Nährstoffbelastung (org. C, Ammonium, Nitrat) in den Untersuchungsgebieten unter verschiedenen Produktions- und Ausbauszenarien gekoppelt. Zur Abschätzung der Nährstoffemissionen aus den potentiellen Farmanlagen wurde das MatLab-basierte Emissionsmodell von van der Wulp (2008) weiterentwickelt. Dieses berechnet die aus den Zuchtbetrieben resultierenden gelösten und partikulären Nährstofffrachten auf Grundlage von Fischart, Fischbesatz, Futtermenge und –qualität sowie Wachstumsgleichungen. Die Simulation der Nährstoffverteilung im Untersuchungsgebiet bei unterschiedlichen Farmgrößen und Produktionsintensitäten bildet zusammen mit entsprechenden Toleranzwerten der Wasser- und Sedimentqualität die Grundlage für die ökologische Nachhaltigkeitsanalyse (sustainability analysis) im DSS.

4.3. Ausbildung und Capacity Building

Begleitend zu den Forschungsaktivitäten des Projektes erfolgten im Rahmen der Masterstudienganges „Coastal Geosciences and Engineering“ sowie des Doktorandenprogramms am CORELAB intensive Ausbildungs- und Weiterqualifizierungsaktivitäten. Die nachfolgende Aufstellung gibt eine Übersicht der in SYSMAR/SPICE II durchgeführten Examensarbeiten. Sieben weitere Graduiertenarbeiten wurden im Rahmen des Vorläuferprojektes/SPICE I abgeschlossen:

Sulastiawan, H.P. (2008): Study of Nutrient distribution in Pegametan Bay, Bali, Indonesia. Coastal Research Laboratory, Christian-Albrechts-Universität. MSc.

Pangkey, H. (2008): Development of hydrodynamic numerical flow model for Pegametan Bay, Bali,Indonesia. Coastal Research Laboratory, Christian-Albrechts-Universität Kiel. M.Sc.

Arimbawa, P. (2008): Contribution of mariculture in Indonesian fisheries, case study: Bali. Coastal Research Laboratory, Christian-Albrechts-Universität Kiel. M.Sc.

Oliveira, A. (2009): Problems and prospects of the interaction between aquaculture and fisheries. Institute for World Economy, Christian-Albrechts-Universität Kiel. M.Sc.

Niederndorfer, K.R. (in prep): Determining maximum production rates for finfish mariculture for sustainable development - a modeling approach. Mathematisch-Naturwissenschaftliche Fakultät, Christian-Albrechts-Universität Kiel. PhD.

Van der Wulp, S.A. (in prep): Developing indicators for sustainable floating net cage culture with respect to dissolved nutrients using numerical modeling. Mathematisch-Naturwissenschaftliche Fakultät, Christian-Albrechts-Universität Kiel. PhD.

Hermawan, S. (in prep): Implementation of the Decision Support System at selected strategic locations in Indonesia. Mathematisch-Naturwissenschaftliche Fakultät, Christian-Albrechts-Universität Kiel. PhD.

4.4. Training

Im Oktober 2009 erhielten zwei Wissenschaftler des Forschungsinstituts GRIM eine 3-wöchige Intensivschulung an der Universität Kiel/CORELAB, im Forschungs- und Technologiezentrum Westküste in Büsum und im Institut für Weltwirtschaft/Kiel. Die Schulung gliederte sich in drei Einheiten:

- Struktur und Anwendung des modularen DSS
- Technik der Hydrodynamisch-numerischen Modellierung
- Methoden der Wasseranalytik

Darüber hinaus wurden in 2009 Trainingseinheiten zur Struktur des DSS, zur numerischen Modellierung und zur Sedimentanalytik in Indonesien vermittelt. Das mehrtägige Training wurde im Anschluss an die Messkampagnen im Forschungszentrum GRIM in Gondol und IMRO-SEACORM in Perancak, Bali durchgeführt.

5. Wissenschaftlicher und technischer Stand, an dem angeknüpft wurde, insbesondere Angabe der verwendeten Fachliteratur sowie der benutzten Informations- und Dokumentationsdienste

Die Nährstoffuntersuchungen wurden nach internationalem Standard für Meerwasseranalytik (Grasshoff et al. 2002) durchgeführt. Die Modellierungsarbeiten erfolgten auf Grundlage der Delft3D-Modellierungssoftware (Delft Hydraulics, 2007). Topographie und Bathymetrie der Untersuchungsgebiete wurden aus vorhandenen nautischen Kartenmaterial (Admiralty Catalogue) und eigenen Erhebungen erstellt. Hauptkonstituenten der astronomischen Tide wurden u.a. aus Daten des globalen TPXO-Tidenmodells (Egbert et al. 1994) extrahiert. Die Kartierung von Landnutzungsmuster wurde im Vorfeld durch Satellitenaufnahmen (Google Earth) unterstützt. Als kritische Grenzwerte für marine Nährstoffbelastung wurden u.a. Schwellenwerte von OSPAR (1998) und HELCOM (2004) adaptiert. Die Definition und Quantifizierung einzelner Kriterien für die Eignungsanalyse eines Gebietes folgte u.a. den Empfehlungen der FAO (1989). Statistiken und Planungsziele zur indonesischen Marikultur wurden u.a. den Berichten des Directorate General of Aquaculture (Anonymous 2004, 2006) entnommen.

Anonymous, 2004: Master Plan Program Pengembangan Kawasan Budidaya laut Departemnet Kelautan dan Perikanan, Direktorat Jenderal Perikanan Budidaya. Jakarta

Egbert, G.D., A.F. Bennett, and M.G.G. Foreman (1994): TOPEX/POSEIDON Tides Estimated Using a Global Inverse Model, J. Geophys. Res., 99, 24821-24852.

Delft Hydraulics, 2007: Delft3D-FLOW User Manual, Version 3.14. WL Delft Hydraulics

Delft Hydraulics, 2007: Delft3D-WAVE, User Manual, Version 3.14. WL Delft Hydraulics

Delft Hydraulics, 2007: Delft3D-WAQ User Manual, Version 4.03. WL Delft Hydraulics

FAO, 1989: Site selection criteria for marine finfish net cage culture in Asia, UNDP/FAO Regional Seafarming Development and Demonstration Project, Network of Aquaculture Centres in Asia. Food and Agricultural Organization, Documentation NACA-SF/WP/89/13.

Grasshoff, K. Ehrhard, M. and Kremling, K., (2002). Methods of seawater analysis, Verlag Chemie Weinheim.

HELCOM, 2004: Measures aimed at the reduction of discharges from freshwater and marine fish farming. HELCOM Recommendation 25/4, 3 pp.

OSPAR, 1998: The common procedure for identification of the eutrophication. Status of the maritime area of the OSPAR convention. NEUT 98/5/1 – Annex 1, OSPAR Strategy to Combat Eutrophication, 7 pp.

Siar, S.V. W. L. Johnston and S. Y. Sim (2002), "Study on Economics and Socioeconomics of Small-Scale Marine Fish Hatcheries and Nurseries, with Special Reference to Grouper Systems in Bali, Indonesia". Report prepared under APEC project "FWG 01/2001 – Collaborative APEC Grouper Research and Development Network". Asia-Pacific Marine Finfish Aquaculture Network Publication 2/2002. Network of Aquaculture Centres in Asia-Pacific, Bangkok.

6. Zusammenarbeit mit anderen Stellen

Über die projektinterne Zusammenarbeit hinaus bestand ein intensiver Informationsaustausch mit verschiedenen regionalen und nationalen Behörden und Forschungsinstitutionen insbesondere auf indonesischer Seite. Hierzu zählten u.a. das Institut for Marine Research and Observation (*IMRO*)/ *SEACORM* in Negara/Bali, das Bogor Agricultural Institute (IPB) und die DAAD-Außenstelle Jakarta. Bezüglich der Definition von sedimentbezogenen Qualitätskriterien der Fischzucht gab es einen engen Wissens- und Datenaustausch mit Dr. H. Yokoyama vom der Fishery Research Agency in Ise/Japan. Ein Besuch des Projektleiters am National Research Institute of Aquaculture fand Ende 2008 statt.

Relevanz und Aktivitäten des Projektes wurden anlässlich eines Besuchs des indonesischen Generalkonsuls für Deutschland, Herr Teuku Darmawan, im August 2008 in Kiel diskutiert. Hierbei wurde u.a. die Entwicklung von Marikultur und Küstenforschung in der Provinz Aceh/Nordsumatra angeregt. Vertreter der dortigen Universität betonten ihr starkes Interesse an einer bilateralen Zusammenarbeit zur Regeneration der universitären Aktivitäten.

II. Eingehende Darstellung des erzielten Ergebnisses

Im nachstehenden Fachbericht (Kapitel V) sind die wichtigsten wissenschaftlichen Ergebnisse zur Entwicklung des DSS zusammengefasst, soweit sie nicht bereits den Zwischenberichten entnommen werden können. Zwecks einer besseren Kommunikation mit den indonesischen Projektpartnern ist der wissenschaftliche Berichtsteil in englischer Sprache abgefasst.

1. Nutzen und Verwertbarkeit des Ergebnisses

Als angewandtes Forschungsvorhaben vereint das SYSMAR-Projekt Perspektiven in Forschung und Wirtschaft. Die Aquakulturwirtschaft wird auch in Zukunft als wichtiger Wachstumssektor der indonesischen Wirtschaft angesehen. Mit dem DSS und den aus der praktischen Anwendung resultierenden Empfehlungen wird eine umfassende, wissenschaftlich begründete Leitlinie für die indonesischen Fachbehörden und für die Marikulturwirtschaft zur Verfügung gestellt, die den Wohlstand der Bevölkerung vor dem Hintergrund einer umweltgerechten Entwicklung im Blickfeld hat. Nach entsprechender Anpassung kann das DSS jedoch auch weltweit in Küstenzonen angewendet werden. So besteht Interesse, das System zur nachhaltigen Entwicklung der Marikultur auch in Süd-Brasilien einzusetzen.

Darüber hinaus stellen die im Laufe des Vorhabens gewonnenen Beobachtungs- und Modelldaten bereits für sich allein genommen eine wichtige Datenbasis für die noch wenig charakterisierten indonesischen Küstengewässer dar, auf die weitere Projekte sowohl mit grundlagenorientierten Forschungsarbeiten als auch mit angewandten Fragestellungen im Bereich des marinen Umwelt- und Naturschutzes sowie im Küstenzonenmanagement aufbauen können.

Über die Einbindung indonesischer Wissenschaftler, Doktoranden, Studenten und Firmen in die Forschungsarbeiten wurde ein Wissens- und Technologietransfer realisiert, der nicht nur der wissenschaftlichen Kompetenz im Partnerland förderlich ist, sondern auch eine gute Basis für zukünftige Kooperationen in Forschung und Entwicklung darstellt. Ein derartiges Netzwerk ist für die erfolgreiche bilaterale Zusammenarbeit im Rahmen eines potenziellen Anschlussvorhabens unverzichtbar.

2. Während der Durchführung des Vorhabens dem Zuwendungsempfänger bekannt gewordener Fortschritt auf dem Gebiet bei anderen Stellen

Entfällt

3. Erfolgte oder geplante Publikationen

Mayerle, R., Windupranata, W. & Hesse, K.J. (2009): A Decision Support System for a Sustainable Environmental Management of Marine Fish Farming. Yang, Y., Wu, X.Z. & Zhou, Y.Q. (eds.) (2009): Cage Aquaculture in Asia: Proceedings of the Second International Symposium on Cage Aquaculture in Asia, 3-8 July 2006, Hangzhou, China (Vol. 2), 370-383. Asian Fisheries Society, Manila, Philippines, and Zhejiang University, Hangzhou, China.

Windupranata, W. & Mayerle, R. (2009): Decision Support System for Selection of Suitable Mariculture Site in the Western Part of Java Sea, Indonesia. ITB Journal of Engineering Science, Vol.41b(1). 77-96.

Windupranata, W. & Hayatiningsih, I. (2009): Optimization of Mariculture Site in the Tourism Area of Seribu Islands, Java Sea, Indonesia. Proceedings of CMT 2009, the 6th International Congress on Coastal and Marine Tourism, 23-26 June 2009, Nelson Mandela Bay, South Africa. 30-137.

Niederndorfer, K.R., van der Wulp, S.A., Mayerle, R., Foders, F., Sugama, K., Hanafi, A., Runte, K.-H. & Hesse, K.-J. (2009): A Decision Support System for Site Selection and Sustainable Development of Marine Fish Farming in Indonesia (Abstract). International Symposium Scottish Aquaculture: A Sustainable Future. 21-22 April 2009, Edinburgh, Scotland. Aquaculture Research, special edition.

Van der Wulp, S.A., Niederndorfer, K.R., Mayerle, R., Hesse, K.-J., Runte, K.-H. & Hanafi, A. (2010): Sustainable Environmental Management for Tropical Floating Net Cage Mariculture, A Modeling Approach. Proceedings of CIGR 2010, The XVIIth World Congress of the International Commission of Agricultural engineering (CIGR), June 13-17 2010, Quebec City, Canada.

Ihsan, Y. N., Hesse, K.-J., Holmgren, N. & Schulz, c. (submitted): A Comparison of Nutrient Fluxes in Monoculture and Polyculture Systems for Shrimp and Seaweed Production. J. World Aquacult. Soc.

III. Erfolgskontrollbericht

1. Beitrag des Ergebnisses zu den förderpolitischen Zielen des Förderprogramms

Das Vorhaben ist dem Cluster 3 „Ökologie und Aquakultur“ des SPICE II –Verbundprogramms zugeordnet, welcher einen wesentlichen Bestandteil der WTZ der Bundesregierung in Meeres- und Geowissenschaften mit Indonesien darstellt. Die im vorliegenden Projekt durchgeführten Forschungs- und Entwicklungsarbeiten stehen im Einklang mit dem im Aktionsplan der bilateralen Kooperation formulierten Ziel, einen anwendungsnahen Beitrag für ein nachhaltiges Umwelt- und Ressourcenmanagement der stark gefährdeten indonesischen Küstengewässer zu leisten. Übergeordnete Zielstellungen der WTZ betreffen die Intensivierung der bilateralen Beziehungen, den Aufbau von wissenschaftlichen Netzwerken, den Ausbau von Forschungskapazität im Partnerland und die Bewusstseinsbildung im Hinblick auf umweltrelevante Problemstellungen. Mit den im Vorhaben integrierten Schulungs- und Trainingseinheiten sowie den projektbegleitenden Aus- und Fortbildungsmaßnahmen für indonesische und deutsche Studenten wurde den o.g. förderpolitischen Zielen entsprochen. Die durch die Projektaktivitäten intensivierten und neu geknüpften Kontakte, die weit über den Kreis der eigentlichen Projektpartner hinausreichen, führten mittlerweile zu einer konzertierten Planung weiterer gemeinsamer Forschungsaktivitäten in Indonesien.

2. Wissenschaftlicher Erfolg des Vorhabens

Insgesamt konnten die im Projekt gesteckten Ziele, auch in Bezug auf die Ausbildungseffizienz, innerhalb der Laufzeit erreicht werden. Als Ergebnis des Vorhabens liegt ein modellgestütztes Entscheidungsfindungssystem (DSS) vor, welches anhand von Nachhaltigkeitskriterien eine ökologisch und sozioökonomisch nachhaltige Raumplanung für die künftige Entwicklung der küstennahen Fischzucht in Indonesien ermöglicht. Die grundsätzliche Konzeption des DSS aus Informations-, Modell- und Managementsystemen mit benutzerfreundlichem Interface ist erfolgreich und kann zur Bearbeitung verschiedenartiger Fragestellungen weltweit im Küstenmanagement angepasst und erweitert werden. Ein Erfolg des Vorhabens liegt auch in der erreichten Ausbildungsperformanz. Aus dem Projekt resultierten 4 Masterarbeiten, die im Rahmen des Master-Studienganges „Coastal Geosciences and Engineering“ der Universität Kiel durchgeführt wurden. Drei Dissertationen sind zur Zeit in Vorbereitung. Als eigenständiges Resultat der Untersuchungen liegen darüber hinaus erstmalig umfangreiche Datensätze, Modellentwicklungen und Karten zur räumlichen Struktur der wesentlichen physikalischen und nährstoffchemischen Parameter für die untersuchten Küstengebiete vor.

3. Einhaltung des Finanzierungs- und Zeitplanes

Der Zeit- als auch der Finanzierungsplan konnte, wie ursprünglich vorgesehen, eingehalten werden. Eine geringfügige Zeitverschiebung gab es in der Terminierung der zweiten Messkampagne, die wegen Krankheit des indonesischen Partners um 2 Monate verschoben werden musste. Die Vertragslaufzeit der beiden Doktorandenstellen wurde kostenneutral um einen bzw. drei Monate verlängert, da zusätzliche Modellierungsarbeiten erforderlich waren.

4. Verwertbarkeit der Ergebnisse

Verwertbarkeit und Nutzen der Projektergebnisse sind in §7 des Schlussberichtes ausführlich dargestellt. Das entwickelte DSS bildet ein strategisches Werkzeug für eine ökologisch und sozioökonomisch nachhaltige Entwicklung zukünftiger Fischzuchtaktivitäten, das im Rahmen der Küstenraumplanung von indonesischen Fachbehörden und der Marikulturwirtschaft genutzt werden kann. Die im Projekt eingebundenen Forschungsinstitutionen profitieren unmittelbar von den Ergebnissen und Empfehlungen. Es besteht auf indonesischer Seite ein starkes Interesse, das DSS auf Fragestellungen der erneuerbaren Energienutzung in Küstengewässern auszuweiten.

5. Erfindungen und Schutzrechtsanmeldungen

Entfällt

6. Arbeiten, die zu keiner Lösung geführt haben

Während die geplanten Zielstellungen im vorliegenden Projekt erreicht werden konnten, ergaben sich aus den Forschungsaktivitäten neue Erkenntnisse, wie eine weiterführende Optimierung des DSS erreicht werden könnte. Ein Engpass des Systems besteht in der oft mangelnden Verfügbarkeit von Felddaten, die erst mit relativ zeitaufwendigen und arbeitsintensiven Messungen erhoben werden müssen. Es sollte daher geprüft werden, welche Informationen aus modernen Fernerkundungstechniken wie TerraSAR-X für das DSS nutzbar gemacht werden können. Forschungsbedarf besteht auch in der besseren Beschreibung des bodennahen Sedimenttransportes, der im Umfeld der Fischzuchtanlagen für die Benthosbelastung eine wesentliche Rolle spielt. Weiterhin sollten biogeochemische Transformationsprozesse, wie Remineralisation, Nährstoffaufnahme und Denitrifizierung in der Modellierung der Wasserqualität verstärkt berücksichtigt werden.

IV. Zusammenfassung

Im Rahmen des SYSMAR-Projektes wurde ein integriertes Decision Support System (DSS) für einen nachhaltigen Ausbau der Fischzuchtaktivitäten in indonesischen Küstengewässern entwickelt. In dem System, welches auf einer Kombination von Felddaten, numerischen Simulationsmodellen und GIS-Datenbanken basiert, werden sowohl umweltrelevante als auch sozioökonomische Entscheidungskriterien zusammengeführt, um eine in beiderlei Hinsicht ausgewogene Entwicklung der Fischzucht zu gewährleisten. Das DSS gestattet eine optimierte Auswahl von Eignungsgebieten zur Ansiedlung von Fischfarmbetrieben und ermöglicht darüber hinaus eine gebietsspezifische Abschätzung der ökologischen Tragfähigkeit sowie der Wirtschaftlichkeit verschiedener Produktions- und Ausbauszenarien.

Zur Demonstration der Leistungsfähigkeit wurde das System auf zwei Gebiete in Nordbali und Sumbawa, die im Rahmen des Entwicklungsplans des DKP für einen zukünftigen Ausbau der Fischzucht vorgesehen sind, angewendet. Mit dem DSS und den aus der praktischen Anwendung resultierenden Empfehlungen wird den indonesischen Fachbehörden und der Marikulturwirtschaft eine wissenschaftlich begründete Leitlinie für ein nachhaltiges Management der Marikultur zur Verfügung gestellt.

Begleitend zu den Forschungsaktivitäten erfolgte eine Intensivierung des Capacity Building durch Trainingskurse in Indonesien und Deutschland sowie Ausbildung im Postgraduierten- und Doktorandenprogramm „Coastal Geosciences and Engineering“ an der Universität Kiel.

V. Fachbericht / Scientific Report

1. System for the sustainable environmental management of floating net cage mariculture in Indonesia

1.1. Introduction

Goal of this project is to further develop and apply the Decision Support System (DSS) for the development and management of sustainable mariculture focused on the Indonesian region which has been created during the SPICE I project phase. The existing DSS was mostly focused on the determination of suitable sites (Mayerle et al. 2006; Windupranata 2006).

During the SPICE II phase we developed a universally applicable methodology for the determination of the carrying capacity for floating net cage finfish mariculture. To do so, the assimilation of farm wastes by the environment is assessed at near-field and far-field scales for particulate carbon and dissolved nitrogen effluent discharges, respectively. Compared to the assimilative capacity of the environment, maximum allowable production rates determine the potential farm sizes locally whereas the regional carrying capacity is expressed as a total production rate for the entire area of interest. First, the methodological steps are highlighted introducing the novelties of the DSS. Additionally, the application of the DSS will be demonstrated for two sites along the North Bali shore line and one site at the island of Sumbawa as described in section 1.4.

1.2. Methodological development of the Decision Support System

1.2.1 Site Selection

The site selection, as developed during the SPICE I phase, narrows down the area of interest to the sites that can physically and technically harbor farms. It utilizes spatial information for key physical and chemical parameters, coastal uses as well as criteria that allow ranking with respect to suitable conditions for a predefined culture type and species. Information of the key parameters is obtained from numerical modeling, databases and field measurements. All information is collected in a Geographic Information System (GIS) and processed by an analytical framework which provides an overview of the scale of suitability for floating net cages within the entire chosen domain.

Parameters and criteria for site selection

A selection of the key parameters which affect floating net cage practice is used to assess the suitability of a site. Criteria are assigned to each parameter describing conditions to be: Optimal, Allowable or Unsuited. These criteria have been adopted from Windupranata (2006) and modified to include coastal usage. An overview of the used parameters and criteria for traditional floating net cage farms is shown in table 1.1. The DSS requires information of the selected parameters which are obtained from numerical models, measurements and field surveys.

Table 1.1: Key parameters and criteria for the definition of suitable floating net cage mariculture.

Group	Parameters	Indicator	Units	Allowable	Optimum
Physical	Minimum cage depth	Minimum water depth	m	> 6	> 8
	Mooring depth	Maximum water depth	m	< 25	< 20
	Exposure to currents	Depth averaged current velocity	$m\ s^{-1}$	< 1	< 0.5
	Cage flushing	Surface current velocity	$m\ s^{-1}$	> 0.05	0.2 – 0.5
	Exposure to waves	Significant wave height	m	< 1	< 0.6
	Exposure to wind	Mean wind speed	$m\ s^{-1}$	< 5	< 5
Chemical	Water Temperature	Water temperature	°C	20 – 33	27 – 31
	Salinity	Salinity	ppt	15 – 35	26 – 31
	Dissolved oxygen	Dissolved oxygen	$mg\ l^{-1}$	> 4	> 5
	Hydrogen Index	pH	$log[H^+]$	6.5 – 8.5	7.8 – 8.5
	Secchi depth	Secchi depth	m	> 2	> 4
	Turbidity	Suspended solids	$mg\ l^{-1}$	< 10	< 5
	Ammonium	NH_4-N	$mg\ N\ l^{-1}$	< 1	< 0.5
	Nitrite	NO_2-N	$mg\ N\ l^{-1}$	< 4	< 4
	Nitrate	NO_3-N	$mg\ N\ l^{-1}$	< 200	< 200
	Ortho-Phosphate	PO_4-P	$mg\ P\ l^{-1}$	< 70	< 70
Sediment	Bottom Sediment type	Classification		Silt / Mud	Sand
ICZM	Villages/Towns	Distance from	m	> 200	> 500
	Land based point source	Distance from	m	> 200	> 500
	Used perimeter	Distance from	m	> 200	> 500
	Rivers	Distance from	m	> 200	> 500
	Navigation lines	Distance from	m	> 200	> 500
	Industrial areas	Distance from	m	> 1000	> 5000
	Touristic areas	Distance from	m	> 500	> 1500
	Protected areas	Distance from	m	> 1000	> 5000

Numerical modeling of hydrodynamics and waves

As already applied in the SPICE I project phase, numerical models of hydrodynamics and waves are used to provide physical information of the area of application. There are several commercial and open source modeling software packages available which can be used for the DSS. We used the Delft3D Modelling Suite. The Delft3D Suite is a fully integrated modeling framework for the simulation, amongst others, flow, waves and water quality. With Delft3d-FLOW, two-dimensional depth integrated or three-dimensional flow models can be developed providing hydrodynamic properties for the area of interest. Bathymetric information is provided and driving forces such as tidal variations and wind are imposed to curvilinear computational grids in order to estimate current velocities and water level variations within the domain. The Delft3d-SWAN model is capable of simulating wave propagation, refraction, shoaling, wind-induced generation and dissipation due to white-capping, depth-induced wave breaking, bottom friction and wave-wave interactions. Similar to the hydrodynamic model, bathymetry is provided for a curvilinear grid and wave and wind conditions are imposed to the domain in order to compute the evolution of random, short-crested waves in the area of interest.

Field surveying: Water quality, sediment characteristics and coastal usage

Previous experiences have shown that physical information forms the basis of the site selection. Completion of the site selection data acquisition is reached when information of water quality, sediment characteristics and coastal usage are given. The water quality information used for site selection is preferably provided by field measurements has also done for the application discussed later on. Even though online databases were previously used, we came to the conclusion that these did not provide the desired accuracy for coastal regions and were therefore abolished. Sediment characteristics are obtained from grab-samples. The status quo concerning the current coastal usage of the domain of interest requires an inventory of settlements, vegetation and land use. An initial analysis of satellite imagery proved to save a lot of time identifying the objects to survey.

Analytical framework

The analytical framework is responsible for the processing of all information into an overview of the suitable sites. Parameter information is collected in spatial grid as ‘unique values’, ‘distance from’ or ‘uniform’ data as illustrated in figure 1.1.

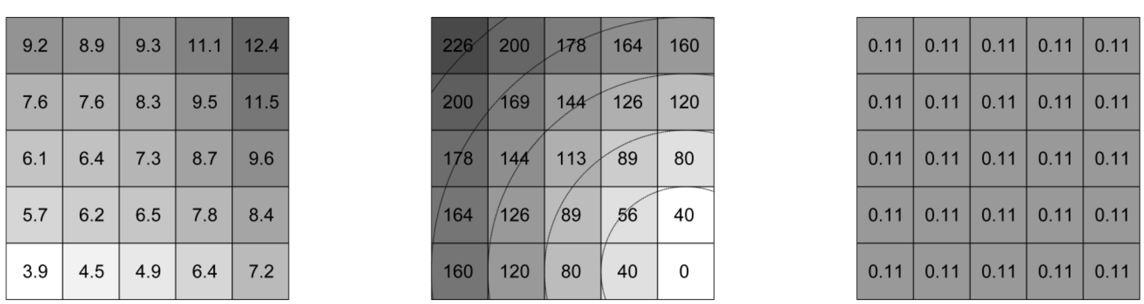


Figure 1.1. Examples of spatial rasters for: a. gridded values where each grid cell has its own value; b. distance

values, each grid cell is assigned the distance from a given location and c. uniform values where the entire grid has one representative value.

Information is reclassified according to suitability criteria into 'Optimal', 'Allowable' or 'Unsuited'. These classes differ from the previously used classification (' Unsuited','Poor','Good' and 'Very good') because of the difficulty to qualitative distinguish many classes. A weighted grid overlay (figure 1.2) is performed with all parameter grids (x_i) yielding the average suitability score (*TS*) ranging between allowable (1) and optimal (2) according to equation 1. The weight (w_i) assigned for each parameter represents the relative level of importance which can be determined by means of Analytical Hierarchy Process (Windupranata 2006).

$$TS = \sum_{i=1}^{n} x_i \cdot w_i \quad (1)$$

A filter is applied in order to exclude unsuited scores. Once a grid cell is unsuited for one of the parameters, the overall score will become unsuited (0). The result provides a spatial representation of the suitable sites for floating net cage mariculture.

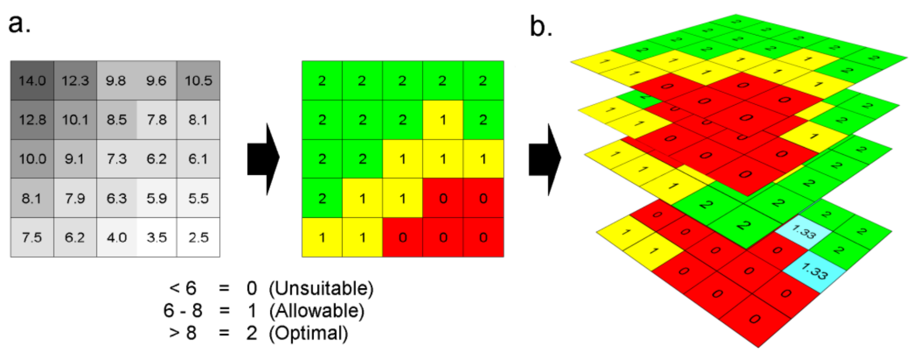


Figure 1.2. Schematic overview of the reclassification and overlay process.

1.2.2 Environmental carrying capacity

Environmental sustainability can be described as the ability of the environment to accommodate a particular activity or rate of activity without an unacceptable impact. Assuming best management practice of floating net cage farms and utilization of proper culture techniques, sustainable practice is limited by its production rate also referred to as the (environmental) carrying capacity. In addition to the work done during SPICE I, the carrying capacity of floating net cages is incorporated at local and regional scale. The release and deposition of particulate organic carbon (POC) is considered to have a potential near-field impact and hence determine the local carrying capacity i.e. the farm size at a given location. In contrast to particulate wastes, dissolved effluents in the form of excreted nitrogen are considered at far-field scale and are used to determine the regional carrying capacity, i.e. the total production for multiple farms allowed within the area of interest. Prior to any of the analysis of carrying capacity, quantification of farm wastes is conducted.

Farm properties and farm wastes

The release of nutrients from floating net cages into the direct environment varies per species, feed type and culture intensity. Quantification is simplified from a temporal growth model (Wulp van der 2007) which was created for the DSS. Annual average nutrient fluxes are determined under the assumption that farm stock within a farm consists of fish from all life stages. The total annual amount of given feed (F) is determined from the annual production rate (P) and the feed conversion ratio (FCR) according to

$$F = P \cdot FCR, \tag{2}$$

The species most commonly found in Indonesian floating net cage farms and also used in the application of the DSS is Tiger Grouper (*Epinephelus fuscoguttatus*). Alongi et. al. (2009) has observed farms in the Indonesian region for the grow-out of this species, that used trash fish feed and formulated feed with feed conversion rates of 7.78 and 2.64, respectively. That same study indicated composition of the trash fish feed with respect to carbon (C_F) and nitrogen (N_F) are 13.1 and 3.95%. For formulated feed this is 19.6 and 4.6%. The share of feed loss (λ_{wasted}) associated with trash fish feed can be in the order of 60% (Leung 1999; Wu 2000). Formulated feed loss lays in the order 25% as derived from Alongi et. al. (2009). The amount of wasted carbon (C_{wasted}) can be determined by

$$C_{wasted} = F \cdot C_F \cdot \lambda_{wasted}, \tag{3}$$

Assuming 20% of the consumed feed being discarded by the fish as faecal matter (λ_{faecal}) as found for non-tropical species by Hevia (1996) the amount of faecal carbon is expressed as

$$C_{faecal} = F \cdot C_F \cdot (1 - \lambda_{wasted}) \cdot \lambda_{faecal} , \tag{4}$$

The quantity of excreted nitrogen ($N_{excreted}$) is estimated to be in the order of 63% (λ_N) from the quantity of ingested feed as observed by Leung et. al. (1999) and thus is computed as

$$N_{excreted} = F \cdot N_F \cdot (1 - \lambda_{wasted}) \cdot \lambda_N, \tag{5}$$

Indonesian farm practice uses trash fish as their prime feed. Nonetheless part of the feed may consist of formulated feed. In the DSS, 100% trash fish and 70-30% trash fish and formulated feed diets are used in the application. Table 1.2. shows the wastes arising from the production of one ton of fish to represent the production of Tiger Grouper.

Table 1.2.Estimated farm emissions of particulate carbon and dissolved nitrogen arising from culture practice with diets of 100% trash fish and a combination of formulated pellets and trash fish.

	Trash fish (100%)	*Pellets & Trash fish (30-70%)*
C_{wasted}	*1.7 kg C d^{-1}*	*0.97 kg C d^{-1}*
C_{faecal}	*0.21 kg C d^{-1}*	*0.21 kg C d^{-1}*
$N_{excreted}$	*0.2 kg N d^{-1}*	*0.18 kg N d^{-1}*

The farm volume and area needed for the production of one ton of production is determined by the stocking density. The common stocking density for Tiger grouper is 10 kg m^{-3}. Since floating net cages measure 3x3x3 m per cage, the volume per cage equals 27 m^3 and the surface area is 9 m^2, the production of one ton requires a surface area of 33.3 m^2. Nonetheless, the grow-out period for Tiger Grouper is only 300 days and hence on an annual average fewer cages are needed than a production period of, for example, one year. A conversion of $^{300}/_{365}$ corrects the farm area to 27 m^2 per ton of production.

Local carrying capacity based on particulate wastes

Local carrying capacity is determined based on the fate of particulate carbon. The rate of deposition beneath net cage farms is governed by the amount of wastes and physical characteristics of the farm site as illustrated in figure 1.3. Advective transport displaces particles coinciding with the water movement while diffusion refers to the movement of particles due to turbulence. Particles settle at a rate corresponding to its submerged weight and shape. Friction at the sediment boundary layer affects the deposition rate of particles. High friction may prevent particles from deposition and may cause resuspension into the water column inducing further transport of mass.

In order to practice sustainable mariculture, carbon deposition should not exceed a critical level. Existing studies indicate organic carbon decomposition to be in the range of 1 – 5 g C m^2 d^{-1} (Angel et al. 1995). Within the previous SPICE project, a deposition threshold of 1.5 g C m^2 d^{-1} was found (Krost 2007). The DSS will adopt these values as the range of deposition at which farm impacts are limited.

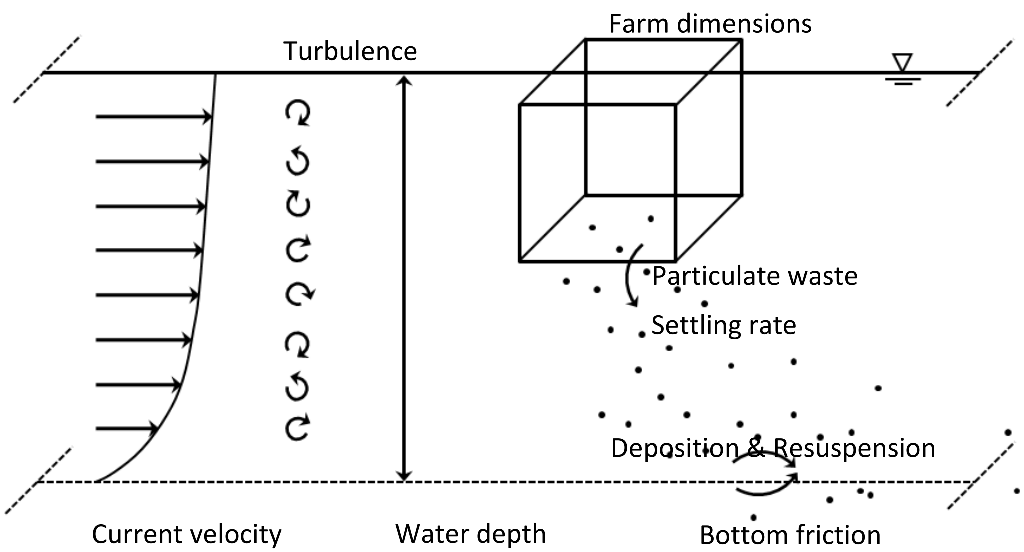


Figure 1.3. Particulate farm waste under influence of: Farm volume and stocking density, current velocities, water depth, shear forces that act on the particles water turbulence and settling characteristics of the particles.

A numerical approximation can be obtained by coupling hydrodynamic model results with deposition model simulations. The Delft3D water quality model is able to incorporate all the above mentioned processes at high spatial and temporal resolution to provide an understanding in the fate of particulate carbon discharged from farm locations for any given scenario. Yet, a simulation has to be repeated for every individual scenario and is thus too complicated for application purposes within the

DSS. We therefore are of opinion that it is important to make a simplification which is able to provided deposition potential for each condition within the entire domain.

Initially, we conducted such simplification by adapting the 'Index of Suitable Location' as proposed by Yokoyama et. al. (2004) based on empirical relations between deposition of carbon and hydrodynamic characteristics of water depth and current velocity. The relation of increased water depth and velocity with increased carrying capacity was clearly shown by model simulations as indicated in by Van der Wulp (2010). Yet again, this relationship only incorporated depth and current velocity but changes to farm properties required a new analysis and hence did not fulfill the needs for practical application of the DSS.

A more deterministic simplified model is chosen, adapted from Gowen et. al. (1989) and Gillibrand et al (1997), which incorporates advection, diffusion and farm characteristics under the assumption of uniform depth and flow. Assuming a constant settling rate (w_s), the temporal mean water depth (h) becomes characteristic for the time a particle takes to reach the bottom. Displacement by the temporal mean and depth averaged current velocity ($\bar{u}$) yields the travelling distance of particles through advection (6) in the current direction ($D_{advection}$). The diffusion coefficient (*E*) can be approximated from the depth and current velocity according to equation 7 (Deltares 2009). The diffusion rate is multiplied by the time a particle is exposed to diffusion as a function of depth and settling velocity. The diffusion distance ($D_{diffusion}$) is expressed as the radius of the diffusion area (8).

$$D_{advection} \approx \bar{u} \cdot \frac{h}{w_s} \tag{6}$$

$$E \approx \bar{u}^{0.8} \cdot h^{1.2} + E_{background} \tag{7}$$

$$D_{diffusion} \approx \sqrt{\frac{E}{\pi} \cdot \frac{h}{w_s}} \tag{8}$$

The approximate deposition footprint can be considered as an ellipse around the distribution area as shown in figure 1.4. Assuming a reoccurring tidal current with a principal direction, advective transport predominates along the x direction. Diffusion occurs multidirectional and hence is considered for both x and y direction. Initially, particulate wastes are distributed over the farm area. Hence, farm dimensions parallel (D_{xfarm}) and perpendicular (D_{yfarm}) to the current direction are added to the displacement of particulate wastes. The footprint area, $A_{footprint}$, is determined according to expression 9.

$$A_{footprint} \approx \pi \cdot \left(½ \cdot D_{x\ farm} + \bar{u} \cdot \frac{h}{w_s} + \sqrt{\frac{E}{\pi} \cdot \frac{h}{w_s}} \right) \cdot \left(½ \cdot D_{y\ farm} + \sqrt{\frac{E}{\pi} \cdot \frac{h}{w_s}} \right) \quad (9)$$

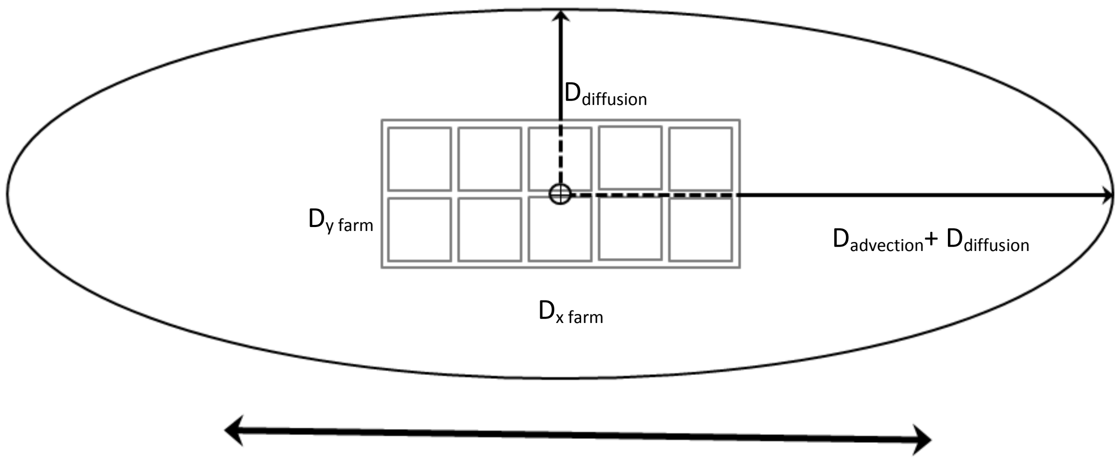


Figure 1.4: Footprint area determined from farm dimensions, advective and diffusion distances $D_{x,y\ farm}$, $D_{advection}$ and $D_{diffusion}$.

The total particulate carbon load is distributed over the deposition footprint, the mean deposition per unit area (D_{mean}) is the total farm load (POC_{farm}) divided by the footprint area (equation 10). The maximum deposition (D_{max}) should occur within the footprint area and is influenced by the variation in current magnitude and direction. A correction from mean to maximum deposition was incorporated as alpha (α) as shown in equation 11 and is to be determined empirically from a hydrodynamic and deposition model.

$$D_{mean} \approx \frac{POC_{farm}}{A_{footprint}} \quad (10) \qquad D_{max} \approx \alpha \cdot \frac{POC_{farm}}{A_{footprint}} \quad (11)$$

A number of simulations were conducted using the Delft3D suite for flow and deposition of the Pegametan Bay area which will be later described in section 1.1. Farm waste discharges were placed randomly over the domain providing unique hydrodynamic characteristics for each location. The range of different settings which were used for 2D and 3D simulations is shown in table 1.3. Results were used to determine alpha (α) for maximum deposition and comparison of the performance of the simplified approach.

Table 1.3. Ranges of different model settings done for comparison between 2 and 3-dimensional hydrodynamic deposition modeling using Delft3D and the simplified approach.

Parameter		Range
Carbon load per unit farm area	$g\ C\ m^{-2}\ d^{-1}$	0.14 – 0.66
Farm area	m^2	524 – 633
Dispersion coefficient	$m^2\ s^{-1}$	0.2 – 4
Average water depth	m	2 – 42
Settling Velocity	$m\ s^{-1}$	0.005 – 0.1
Depth averaged flow velocity	$m\ s^{-1}$	0.003 – 0.07
Critical shear stress for sedimentation	$N\ m^{-2}$	0.002 – 0.004
Critical shear stress for resuspension	$N\ m^{-2}$	0.004 – 0.018

The simplified approach was able to reproduce the Delft3D maximum deposition rates with an average error of 0.28 and 0.7 g C $m^{-2}\ d^{-1}$ for 2D and 3D model results, respectively (Figure 1.5) using an alpha of 1.15. The DSS applies the simplified approach on stepwise increasing production rates for the entire domain based on temporal averaged water depths and current velocities. Local carrying capacities are then determined for each location based not exceeding the given deposition thresholds of 1, 1.5 or 5 g C $m^2 d^{-1}$.

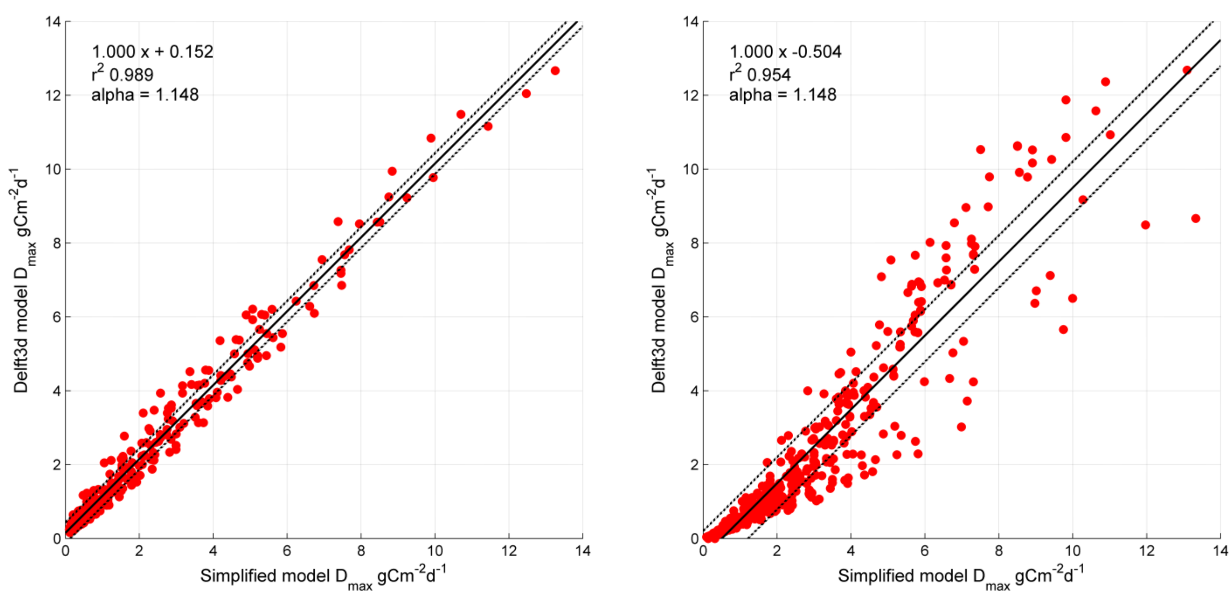


Figure 1.5: Correlation between the D3D coupled deposition model and the simplified model for 2D (left) and 3D (right) results.

1.2.3 Regional carrying capacity based on nitrogenous wastes

In contrast to particulate wastes, dissolved substances such as nutrients discarded from floating net cage farms are transported over greater distances. With sufficient flow rates, nutrient levels around floating net cage fish farms are generally not enhanced significantly yet the accumulation due to multiple farms may be considerable, dependent on the total discharge. In the present approach the carrying capacity for floating net cage fish farms within a domain is proposed to be equivalent to emission rates of total dissolved nitrogen (TDN) not exceeding 1% of the total dissolved nitrogen flux of the domain (Ladwig et al. 2007). This threshold constitutes a pragmatic approach which is currently under discussion. The maximum daily TDN load (TDN_{max}) is calculated on the net flushing (Q_{in}, $m^3 d^{-1}$) and TDN background concentrations (C_{tdn}, g N m^{-3}) (12).

$$TDN_{max} = 0.01 \cdot Q_{in} \cdot C_{tdn} \tag{12}$$

1.3. User interface

The DSS methodology is integrated in a graphical user interface (GUI) constructed with MATLAB. It allows the collection of information from the necessary data sources and provides a fast analysis and overview of DSS results. The GUI contains several databases for quick access and is equipped with a Geographic Information system (GIS) to process and visualize spatial information. Navigation through the DSS is possible by choosing the buttons at the top of the interface (Figure 1.6). An integrated database holds information for different types of: farms, feeds and fish species. Under the "databases" menu item all databases entries can be added, modified or removed.

Figure 1.7 shows the farm properties section which allows the user to select the farm type that is used for decision purposes. Of a given farm size, investments and running costs are specified that are valid for the region the DSS is applied to. Similarly, a selection of targeted fish species and used feed types is made from the information that is available from the relevant databases. Additionally, prices are given which are valid for the local market (Figure 1.8). The selected combination of fish species and feed types allows the DSS to determine the production characteristics per ton of production.

Site selection criteria are defined in the table shown in figure 1.9. The fields contain a description of the parameter; the indicator and the units; the used statistic and the allowable and optimal ranges. The ranges are consists of numbers and logical operators (-, <, >, <= and >=, ==, ~=).

The "Site selection" tab consists of a Geographical Information System (GIS) that collects the spatial information of each parameter and converts them into reclassified suitability classes according to the site selection criteria. Data can be added from different sources, copied and removed (Figure 1.10.).

The carrying capacity tab allows the determination of carrying capacities based on particulate carbon and soluble nutrients. The results yield a map of the environmental carrying capacity within the domain (Figure 1.11). Farm locations can be selected by adding farms (manual or auto). For each farm, the suitability analysis, and carrying capacity is summarized including needed farm area and economic analysis. A total overview is provided in the "Results" section.

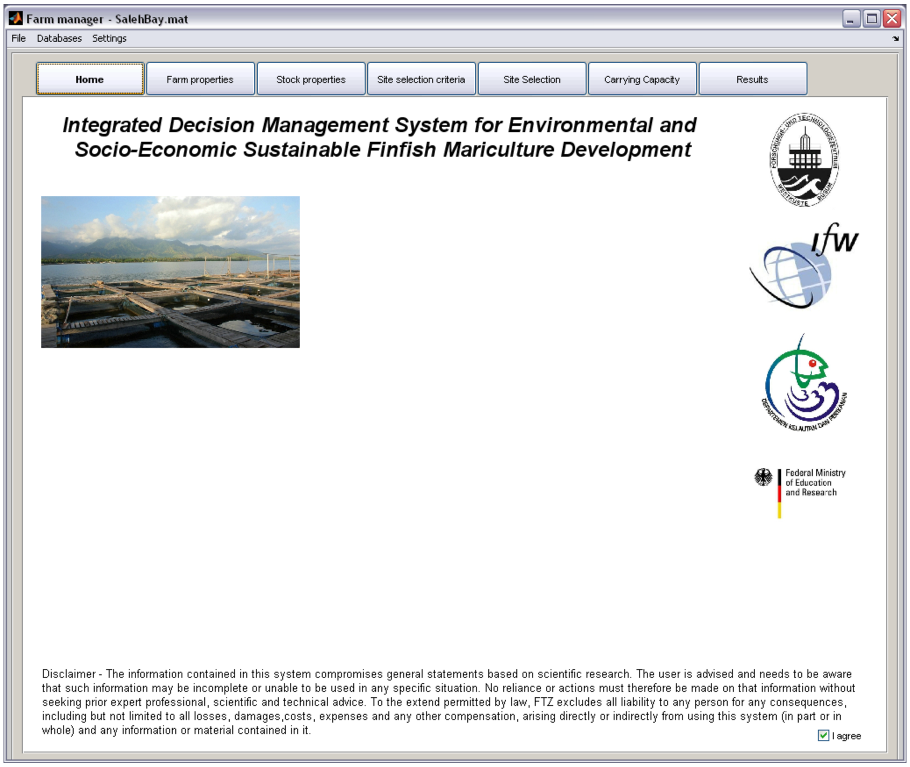


Figure 1.6. The opening screen of the DSS user interface gives an overview of the developing parties involved, a brief description and the user agreement.

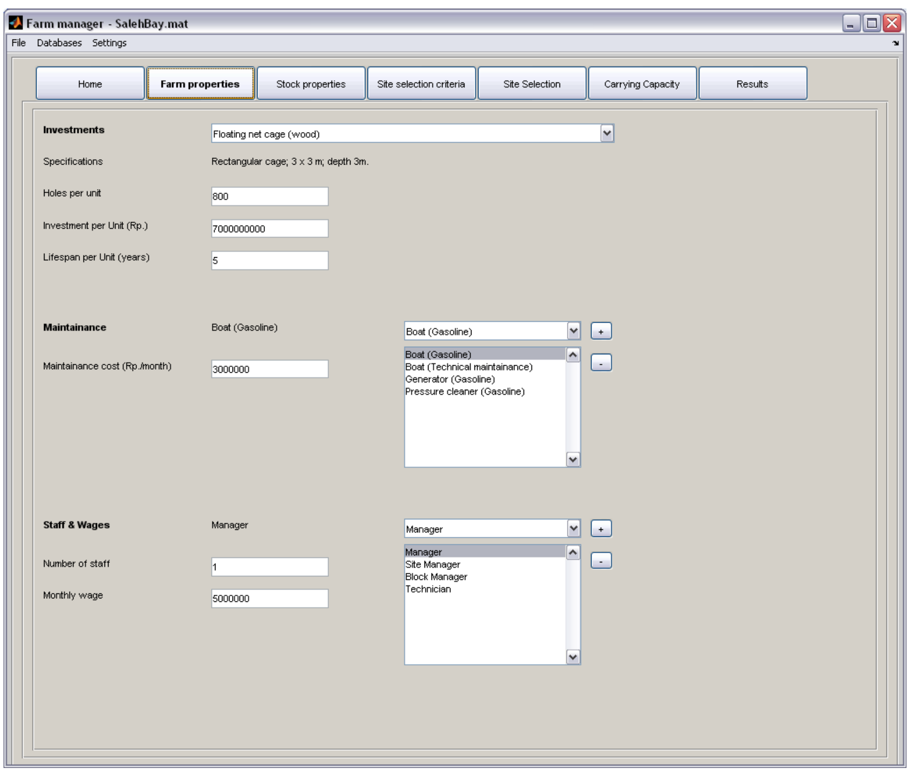


Figure 1.7. Farm properties tab allows a specification of farm type and dimensions as well as a description of the investment, maintenance cost and wages of a representative farm unit.

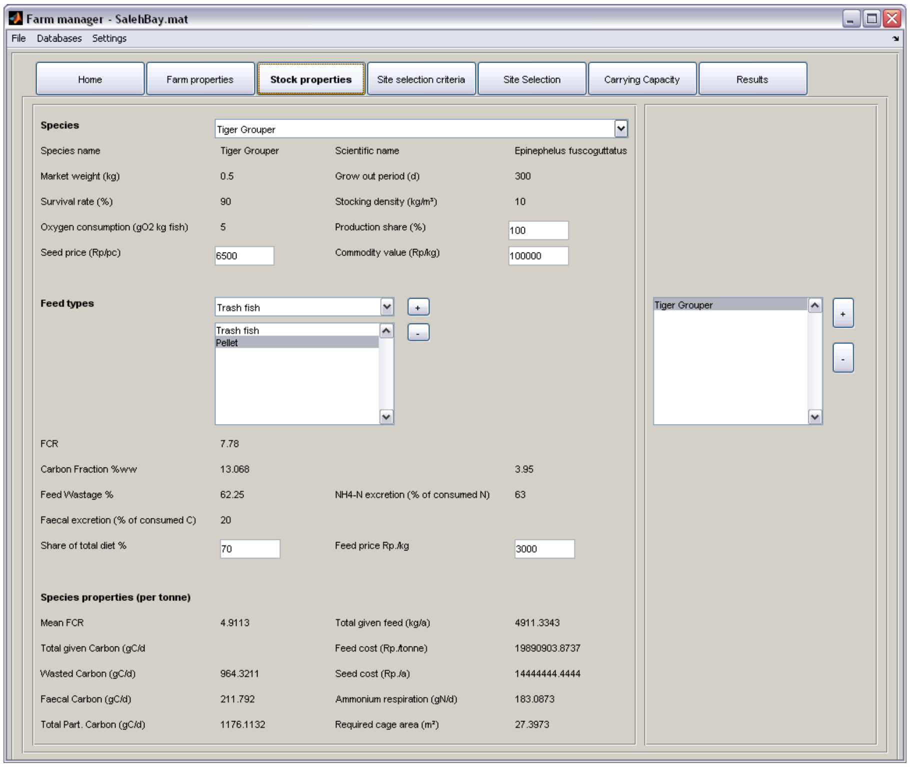


Figure 1.8. Stock properties interface. Species and feed types are read from the database and used to compute waste characteristics and revenue for each ton of production.

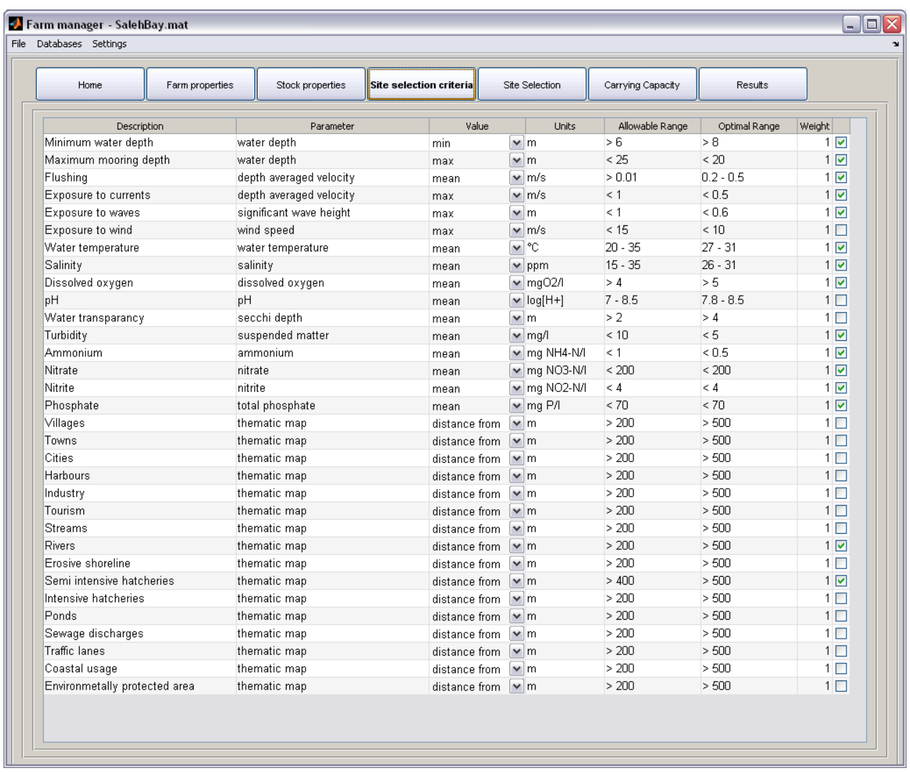


Figure 1.9. Site selection criteria for floating net cage mariculture. Optimal and allowable ranges are given for key parameters which describe suitable conditions required for successful culture practice.

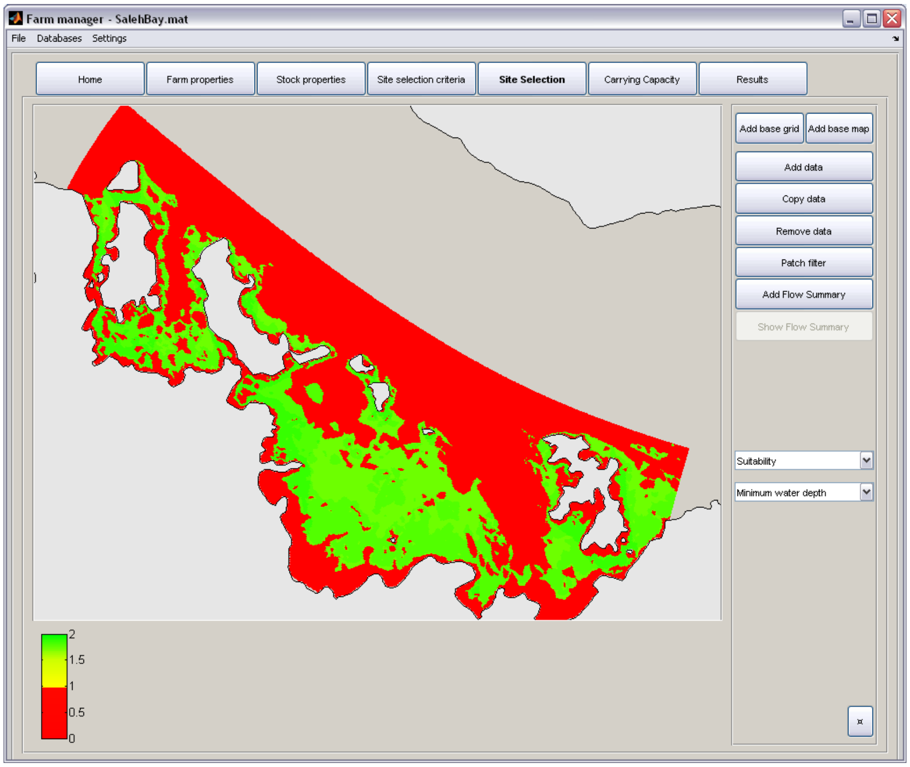


Figure 1.10. Geographical Information Interface (GIS) responsible for processing the spatial data for site selection. Spatial data can be added, copied and removed in order to create the layers of the different parameters which are used for site selection of floating net cage mariculture.

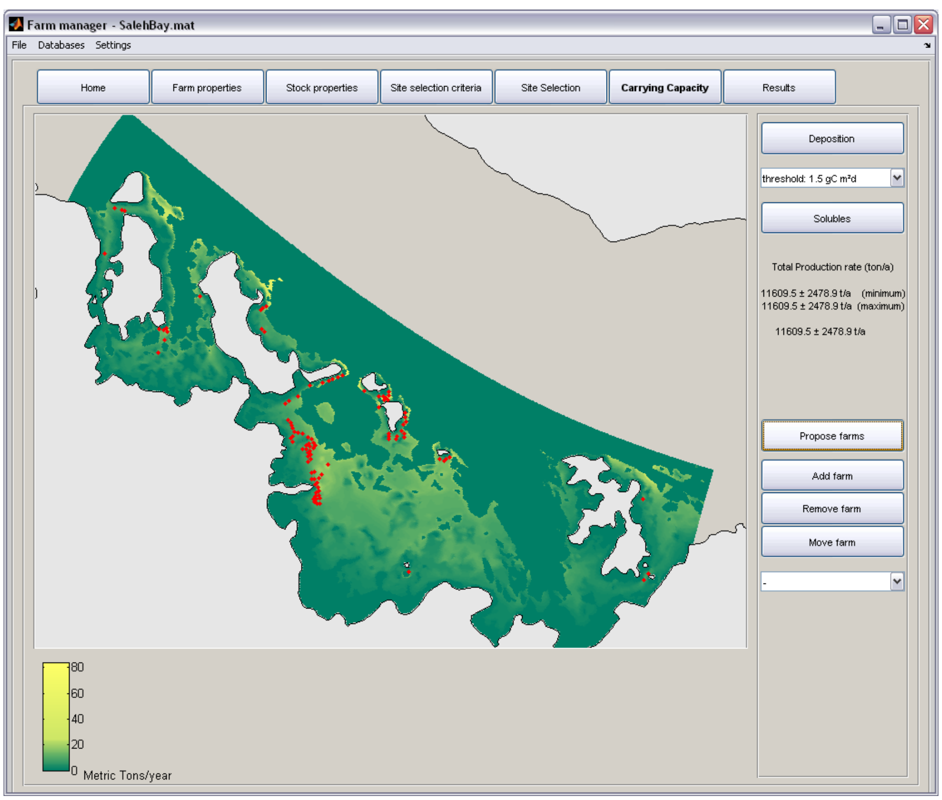


Figure 1.11. Geographical Information Interface (GIS) responsible for processing the spatial data for carrying capacity. Farm arrangements are verified and compared to the various types of carrying capacity.

1.4. Application of the DSS

The decision support system was applied to three selected regions in Indonesia that are of interest for the development of floating net cage finfish mariculture (Figure 1.12). Pegametan bay is located at the North-West coast of Bali, Indonesia (8.13°S 114.6°E) and covers an area of roughly 2200 ha. Since 2001, sixteen farms were established in the area for the grow-out production of predominantly Tiger Grouper (*Epinephelus fuscoguttatus*). The Celukanbawang area (8.15°S 114.71°E) lies to the east of Pegametan Bay and stretches 18 km along the coastline towards the town of Celukanbawang. This stretch of north Bali coastline harbors several pearl farms and hatcheries but hold no floating net cages. Saleh bay is situated at the island of Sumbawa (8.6°S 117.8°E), relatively remote with less infrastructure and facilities as the Bali regions. Currently only three farms are operating in the ~80 km stretching bay.

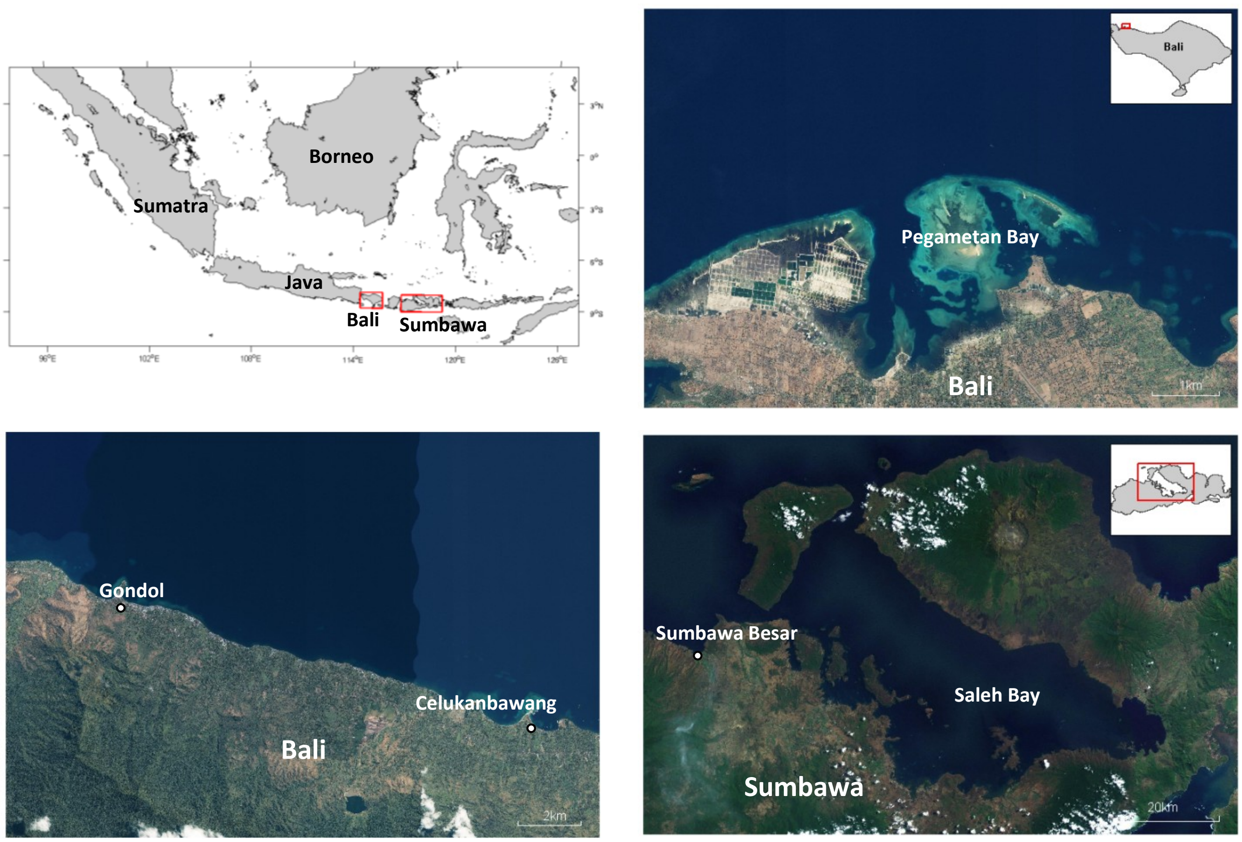


Figure 1.12. The three selected regions for application of the DSS for sustainable floating net cage mariculture development. Pegametan bay and Celukanbawang at the North Bali coast and Saleh bay at Sumbawa Island, 2nd island east of Bali. Satellite Imagery from Yahoo maps.

1.4.1 Application of the Decision Support System to Pegametan Bay

Hydrodynamic model

A hydrodynamic model was set up for Pegametan Bay using the Delft3D Modelling System. Three curvilinear grids were coupled with grid resolutions in the horizontal reducing from 800 meters in the outer parts to 50 meters in the area of interest (Figure 1.13). Tidal astronomic constituents from the TPXO database were used to compute water level variations which were imposed along the northern and southern boundary of the domain to drive the model. Bathymetric information for deep region was taken from the GEBCO online database. Near shore bathymetric data was provided by nautical maps and measurements of the Indonesian National Surveying Institute. Water level measurements were used for model calibration. Predicted water levels in the area of interested coincided with measurements with an average error of 0.06 m (Figure 1.14). The resulting flow fields in the area are exemplarily shown in figure 1.15 for ebb and flood flow conditions. Model results used in the DSS covered a period or about 14 days including neap and spring tide conditions.

Wave model

To obtain estimates of the wave conditions in the Pegametan Region, a wave model was developed using the curvilinear grids from the hydrodynamic model. The worst case scenario for wave impacts would most likely be initiated by winds blowing from northerly directions. Wave model simulations were carried out for such conditions. Six-hourly wind reanalysis data from the NCEP database was analyzed for a 50 year period (1960-2010) in order to identify extreme wind events (NOAA/OAR/ESRLPSD 2009). The analysis showed a maximum wind speed up to 12 m s^{-1} from north-eastern direction (Figure 1.16) with a duration of ~6 hours and occurred only once over the 50 year period. Open boundary wave heights and wave periods were read from the nomogram for deep water significant wave predictions (US Army Corps of Engineers 1984). The extreme event resulted in a significant wave height of 1.9 m with a period of 6.25 seconds. Imposing these conditions to the model domain yielded an estimate of the significant wave heights approaching the North Bali shoreline.

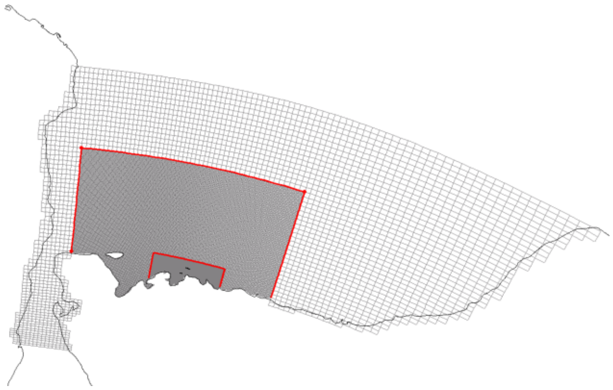


Figure 1.13. Pegametan Bay hydrodynamic model grids. Each grid increases in resolution providing a 50 m cell size in the area of interest.

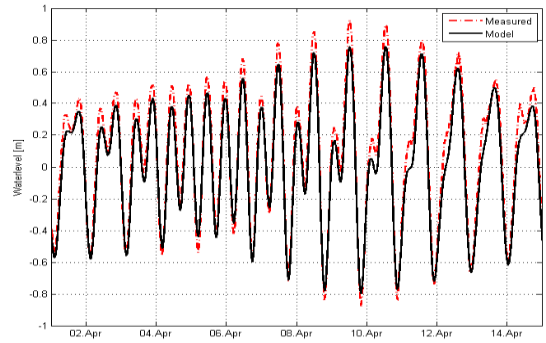


Figure 1.14. Comparison between measured and modeled water level data.

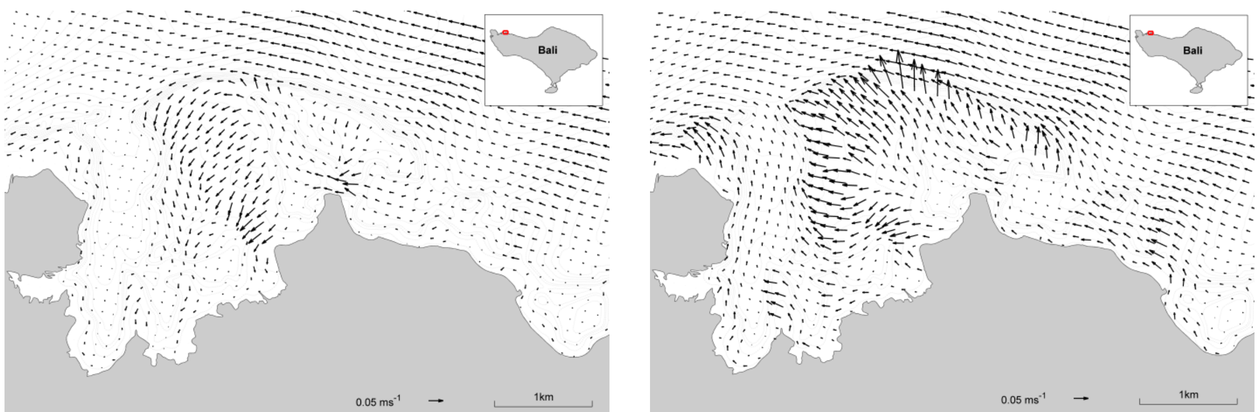


Figure 1.15. Modelled flow field in Pegametan Bay under flood (left) and ebb flow (right) conditions.

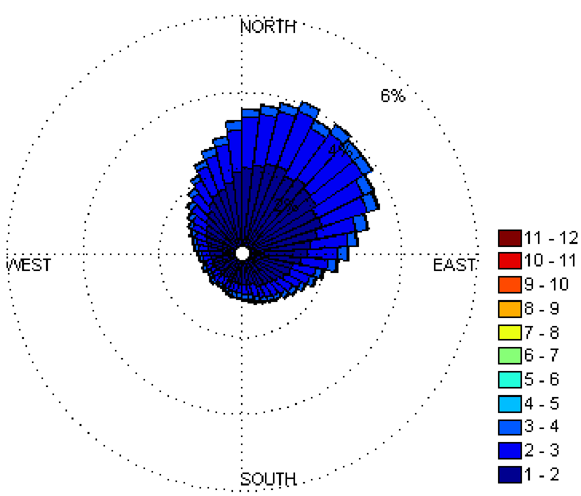


Figure 1.16. Wind rose of the reanalysis data for the period 1960-2010 (NCEP, 2010) distribution for the North Bali Region (m s^{-1}). Extreme wind conditions were found from north eastern direction with a magnitude of 12 m s^{-1}. According to the NCEP dataset this event occurred only once in the period 1960-2010.

Field measurements and surveying

Water quality samples were taken during several measuring campaigns in the period 2008 and 2009 at various locations inside Pegametan Bay. Water samples were analyzed for ammonium, nitrite, nitrate, phosphorus and suspended solids according to Grashoff et al. (2002). Additionally salinity, dissolved oxygen and secchi depths were available for seven stations monitored in the period June 2006 – August 2008 by the Gondol Research Institute for Mariculture. Sediment samples were taken at various locations and classified according to sediment type. Landmarks relevant for the DSS were identified during field surveys and using satellite maps of the various online databases.

Site selection

Reclassification of the physical information obtained from hydrodynamic and wave models gave an insight in the spatial distribution of areas which are suited for the development of floating net cage mariculture. Water depth criteria eliminated shallow waters, reefs and deeper offshore regions. Current velocities were generally found to be lower in the western part of the bay leading to unsuited areas.

Significant wave heights from the worst case scenario identified the most sheltered and suitable areas for the placement of floating net cages to be in the inner regions. Wind speeds over the analyzed fifty year period averaged 1.86 ± 0.87 ms^{-1} and thus remain below the threshold of 5 m s^{-1} for most of the time.

Within the area of interest four shrimp farms outlets were identified. In the western region however, many shrimp ponds were abandoned. An algae farm is situated in the western channel. One small village lies at the coast in the center of the domain. Touristic areas were identified based on the presence of hotels which were only found outside the domain at distances which did not affect the suitability of the area. Two small streams are situated in the eastern zone of the domain which during monsoon periods may discharge significant quantities of runoff water. Figure 1.17 shows the suitability maps of all physical parameters as well as coastal usage and influences as described above.

The spatial, but moreover, the temporal distribution of water quality and sediment samples was too little to develop a generic map of the entire area. Hence, the statistical mean of observed parameters were used to assign a judgment for the entire region. All water quality and sediment type parameters fell within the optimal or allowable range (Table 1.4) and did not contribute to the exclusion of suitable areas.

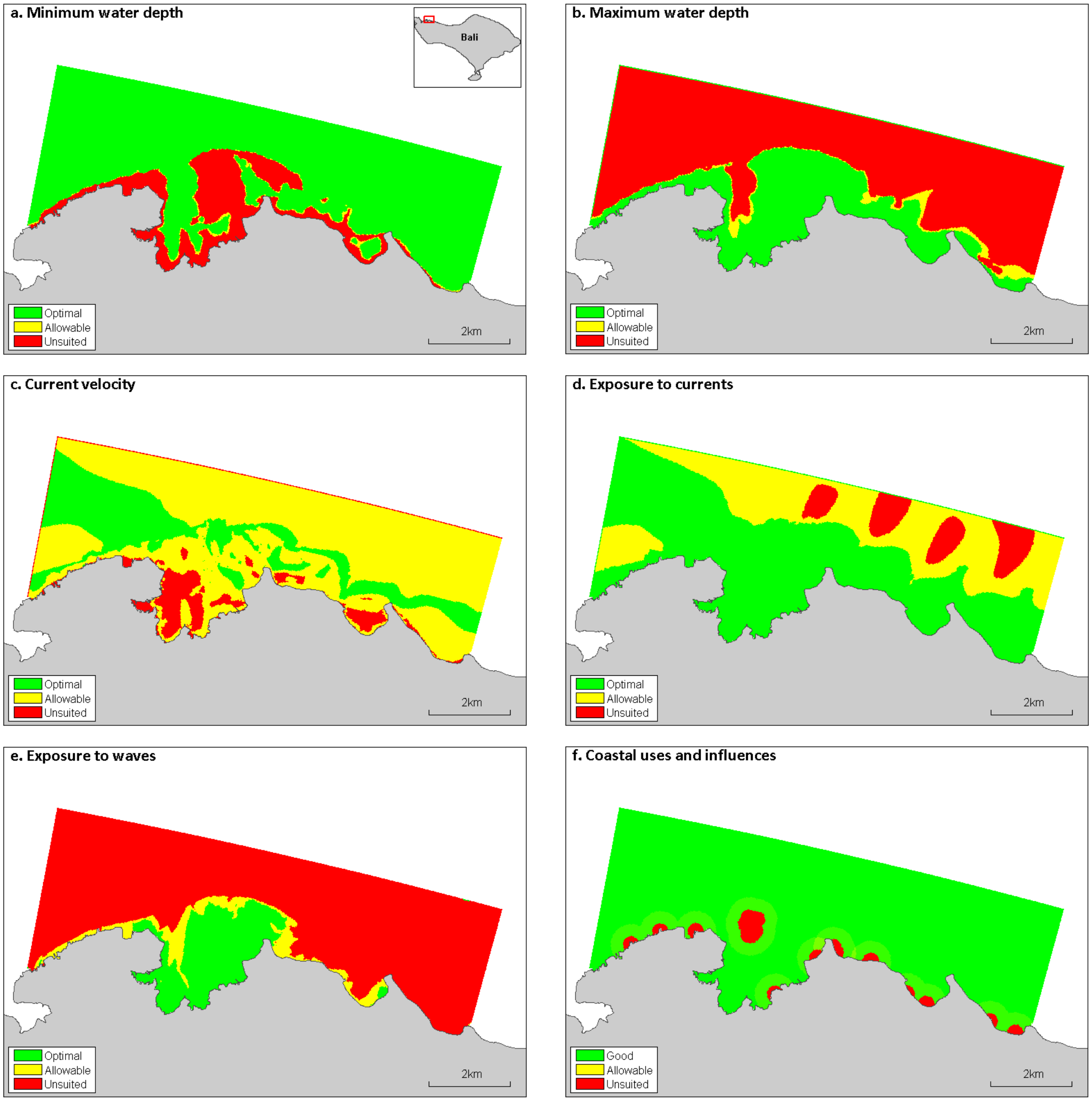


Figure 1.17. Suitability maps of Pegametan Bay for: a. Minimum water depth, b. Maximum water depth, c. Current velocities, d. Exposure to currents, e. Waves and f. Coastal usage and land based influences.

Table 1.4. Ranges of observed water quality and sediment types for suitability analysis.

Parameter		Mean ± std	n-samples	Suitability score
NH_4	mg N l^{-1}	0.0082 ± 0.0049	42	Optimal
NO_2	mg N l^{-1}	0.00087 ± 0.00068	53	Optimal
NO_3	mg N l^{-1}	0.0041 ± 0.0040	53	Optimal
PO_4	mg P l^{-1}	0.0056 ± 0.0039	53	Optimal
TSS	mg l^{-1}	1.9 ± 0.89	8	Optimal
Dissolved Oxygen	mg l^{-1}	5.6 ± 0.58	180	Optimal
Salinity	ppt	33 ± 7	180	Allowable
T	°C	29 ± 1.2	180	Optimal
Secchi depth	m	8.9 ± 5.0	174	Optimal
pH	log [H^+]	8.0 ± 1.5	180	Optimal
Sediment type		Silty - Sand	72	Allowable

The grid overlay resulted in a suitable area of around 90 hectares concentrated on two large perimeters as shown in figure 1.18. Current farm locations coincide with the suitable areas found by the DSS, mostly because of suitable depths. Three existing farms lies in areas marked as unsuited due to current velocities which were lower than prescribed by the adopted criteria.

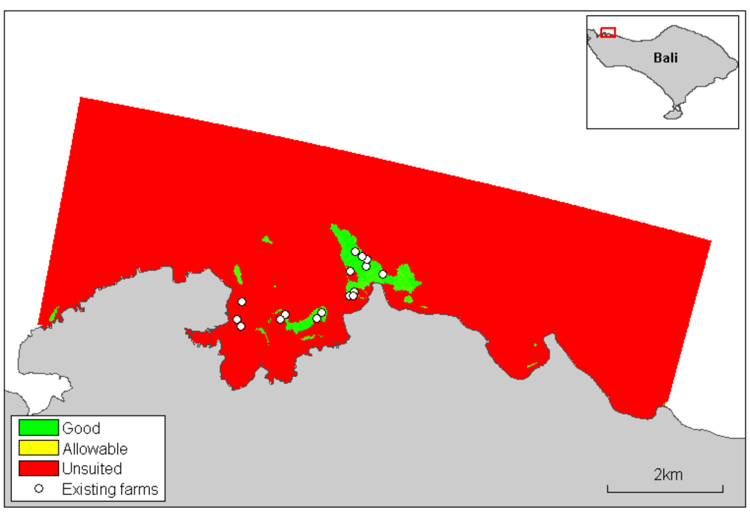


Figure 1.18. Suitability map for Pegametan Bay. About 90 hectares of Pegametan Bay are suited for floating net cage mariculture based on adopted criteria and used information. The locations of the currently existing farms are plotted as white dots.

Local carrying capacity

The local carrying capacity based on particulate matter was estimated for each grid cell based on the mean depth and current velocity as provided by the hydrodynamic model. Settling velocities of 2.6, 6.2 and 2.3 cm s^{-1} were used for trash fish, formulated feed and faeces, respectively (Chu 2000; Rachmansyah et al. 2004). The local carrying capacity varied significantly within the domain. Within the suitable area, higher carrying capacities were found at the entrance of the eastern channel (Figure 1.19). Away from the channel very low carrying capacities (~ 0.5 t a^{-1}) were found in the shallower poorly flushed areas which were even unsuitable when applying low thresholds. A diet of 100% trash fish resulted in maximum farm sizes in the order of 4, 7 and 46.5 t a^{-1} for thresholds of 1, 1.5 and 5 g C m^{-2} d^{-1}, respectively. Substitution of trash fish feed by 30% pellet feed increased maximum production rates to 6.5, 12 and 109.5 t a^{-1} due to a reduction in farm wastes. Increasing deposition thresholds showed a significant increase in carrying capacity.

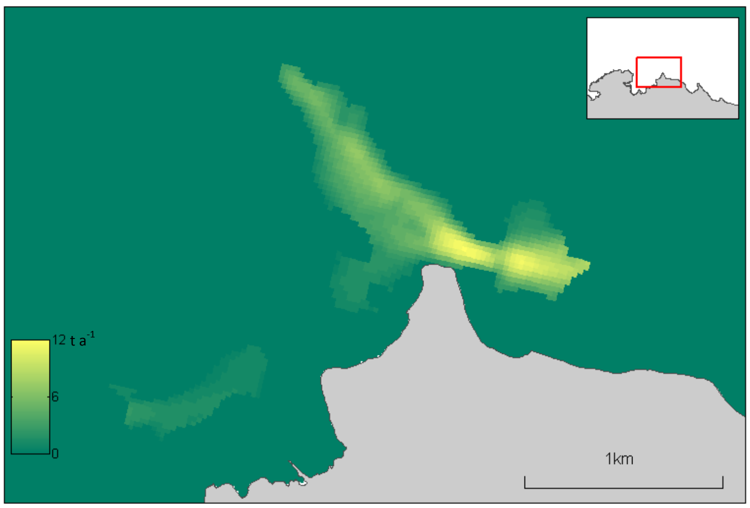


Figure 1.19. Carrying capacity map exemplarily shown for a threshold of 1.5 g C m^2 d^{-1} based on diet composition of 70% trash fish and 30% formulated feed in farms with cages of 3x3x3 m and a stocking density of 10 kg m^{-3}.

Regional carrying capacity based on dissolved nitrogen fluxes

Transboundary flow rates were extracted from hydrodynamic model results for the suitable regions. Total inflow were quantified to be in the order of 2.65×10^7 and 3.62×10^6 m^3 d^{-1} as an average of neap and spring tide conditions for the main suitable domains A and B, respectively, as marked in figure 1.20. Total Dissolved Nitrogen background concentrations were in the order of 0.12 ± 0.037 mg N l^{-1}. Applying the 1% threshold of total N-flux, the maximum allowable daily load was 32.8 ± 9.7 kg N d^{-1} for the eastern and 4.49 ± 1.3 kg N d^{-1} for the western domain, corresponding to regional carrying capacities as shown in table 1.5.

Table 1.5. Carrying capacities based on dissolved nitrogen fluxes where the production rates correspond to the emission of 1% of the areas total nitrogen flux.

Thresholds	Domain A (t a^{-1})	Domain B (t a^{-1})	Total production (t a^{-1})
100 % Trash fish	165 ± 49	23 ± 7	188 ± 55
70 % Trash fish + 30% Pellets	180 ± 53	25 ± 7	205 ± 60

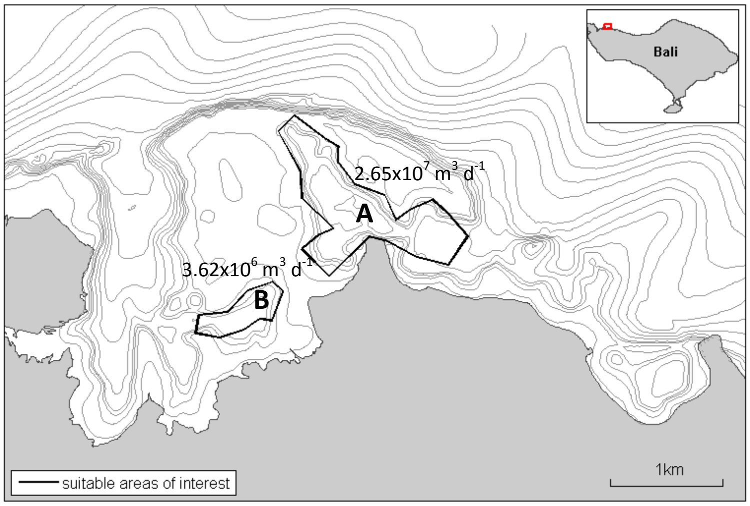


Figure 1.20. Extraction of trans-boundary flow rates from hydrodynamic model results was done for the two suitable domains A and B. Based on the background concentration, the total dissolved nitrogen flux is determined from which the regional carrying capacity is found.

Total carrying capacity and farm arrangement

Farm locations based on the local carrying capacity were proposed with optimal use of the suitable area. Additional to a 200 meter buffer distance between farms, the farm dimensions were considered. Larger carrying capacities yield larger farms occupying greater area. The maximum number of farms is limited by the available suitable perimeter. The number of farms that can be placed within the available perimeter is shown in table 1.6.

Table 1.6. Local carrying capacities for different thresholds and diets. Limitation was applied when the number of farms exceeded the regional carrying capacity.

Diet	Threshold	Minimum ($t\ a^{-1}$)	Maximum ($t\ a^{-1}$)	Farms	Total production ($t\ a^{-1}$)
100 % trash fish	1 $g\ C\ m^{-2}\ d^{-1}$	0.5	4	17	26.5
	1.5 $g\ C\ m^{-2}\ d^{-1}$	0.5	7	18	47
	5 $g\ C\ m^{-2}\ d^{-1}$	4	46.5	15	286.5
	5 $g\ C\ m^{-2}\ d^{-1}$ (limitation)	11	46.5	6	187.5
70 % trash fish	1 $g\ C\ m^{-2}\ d^{-1}$	0.5	6.5	20	44
30 % pellets	1.5 $g\ C\ m^{-2}\ d^{-1}$	0.5	12	19	80.5
	5 $g\ C\ m^{-2}\ d^{-1}$	10	109.5	16	664
	5 $g\ C\ m^{-2}\ d^{-1}$ (limitation)	17.5	109.5	3	204

The total productions of the proposed farms for thresholds of 1 and 1.5 $g\ C\ m^{-2}\ d^{-1}$ remain below the regional carrying capacities and thus are limited to the available suitable space. This is not valid for scenarios with a deposition threshold of 5 $g\ C\ m^{-2}\ d^{-1}$. The number of proposed farms exceeded the regional carrying capacity which leads to a reduction of farms as proposed in figure 1.21. Instead of fewer farms, farm sizes could also be reduced as long as the local and regional carrying capacities remain within the estimated ranges.

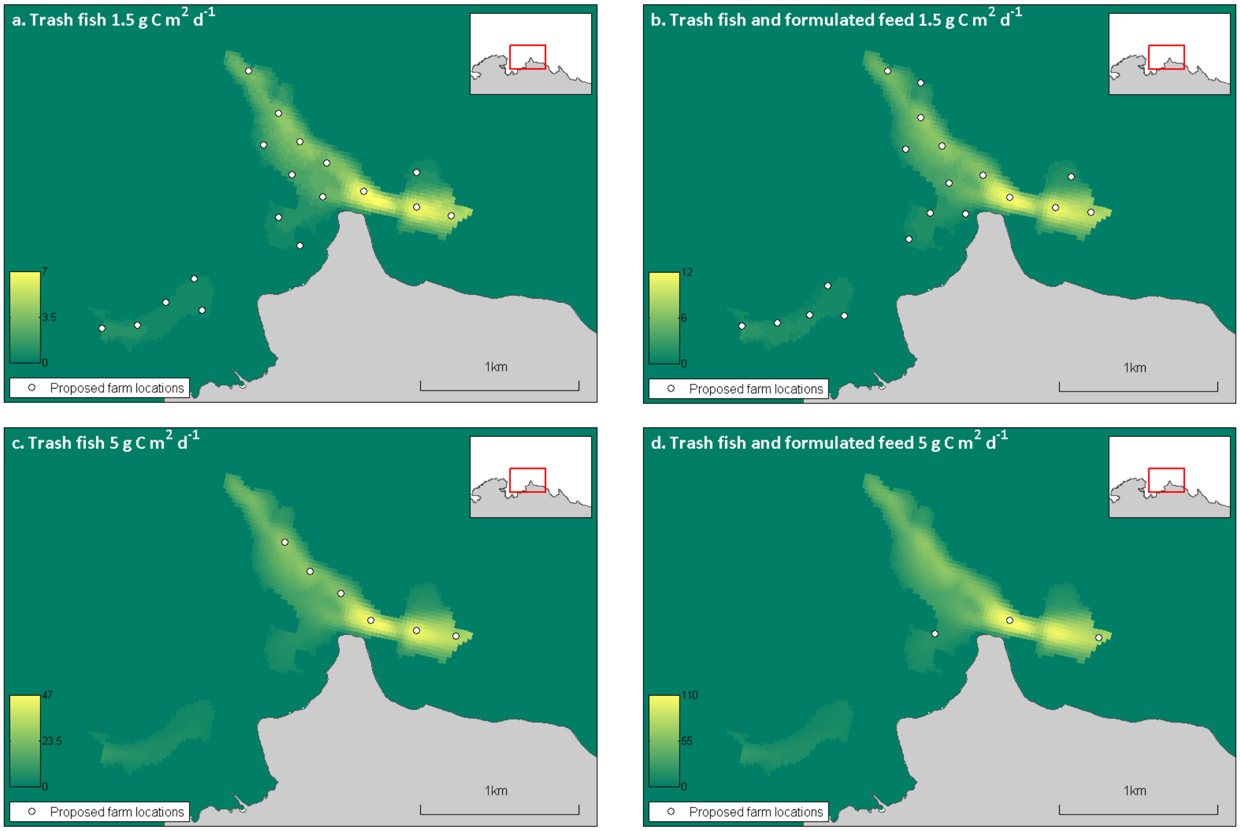


Figure 1.21. Proposed farm arrangement to fit the overall carrying capacity based on available area. The total production for a threshold of 5 g C m^{-2} d^{-1} exceeded the regional carrying capacity based on nitrogen fluxes; the number of farms is thus limited to a total production of around 200 tons as proposed in maps c and d.

1.4.2 Application of the Decision Support System to Celukanbawang

Numerical models

The Celukanbawang hydrodynamic and wave model covers the same domain as the Pegametan model but has a refined resolution of around 50 meters in Celukanbawang area (figure 1.22). Bathymetric information, tidal astronomic constituents and meteorological information as well as model performance are the same as described for the Pegametan area in section 1.4.1.

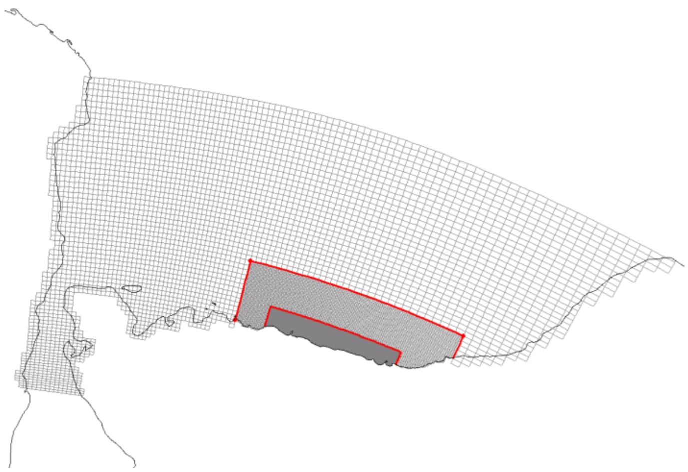


Figure 1.22. Celukanbawang hydrodynamic model grids. Each grid increases in resolution providing a 50 m cell size in the area of interest.

Field measurements and surveying

Water quality samples and sediment samples were taken at several locations along the coast during the period December 2008 - August 2009. Water samples were analyzed for ammonium, nitrite, nitrate, phosphorus and suspended solids. Additionally salinity and dissolved oxygen were measured. Sediment samples were classified according to sediment type. Coastal uses and external influences important to mariculture were identified from satellite imagery and by survey.

Site selection

The grid overlay resulted in a suitable area of 403.6 ha available for the development of floating net cages in the Celukanbawang area as shown in figure 1.23. Low current velocities were only found in smaller confined bays near the Gondol peninsula and around the Celukanbawang harbor. The extreme wave conditions indicated that the north Bali coastline would be exposed to waves higher than 1 meter with an occurrence of once every 50 years, leaving no suitable area for floating net cages (Figure 1.24e). Even though the decision support process would stop at the point where no suitable areas are identified based on the assumptions made, reconsiderations can be made if the user accepts and backs up increased risks. The reconsidered wave scenario was simulated for a wind speed of 6.2 m s^{-1} with a 6 hour duration yielding significant wave heights of 0.7 m and a wave period of 4.2 seconds. According to a statistical analysis of wind events, based on the NCEP wind data this event is likely to be exceeded every five years. This scenario resulted in a wave field approaching the shore with wave heights of 0.7 meters at the domain boundaries and less than 0.6 m closer to the shore and hence leaving the entire area suitable for floating net cages (Figure 1.24 f). The presence of pearl farms as well as land based hatcheries eliminated a great perimeter of suitable area. Additionally, a traffic route for ships is situated in the east of the area. Water quality and sediment type fell within the suitability range (Table 1.7).

Table 1.7. Observed water quality and sediment type adopted for the suitability analysis.

Parameter		Mean ± std	n-samples	Suitability score
NH_4	mg N l^{-1}	0.0024 ± 0.00083	10	Optimal
NO_2	mg N l^{-1}	0.00033 ± 0.00024	10	Optimal
NO_3	mg N l^{-1}	0.0068 ± 0.016	10	Optimal
PO_4	mg P l^{-1}	0.0034 ± 0.0012	10	Optimal
TSS	mg l^{-1}	1.28 ± 0.4	10	Optimal
Oxygen	mg l^{-1}	6.54 ± 0.48	5	Optimal
Salinity	ppt	30.2 ± 0.76	10	Optimal
T	°C	29.5 ± 0.2	5	Optimal
pH	log $[H^+]$	8.4 ± 0.03	10	Optimal
Sediment type		Silty – Fine Sand	5	Allowable

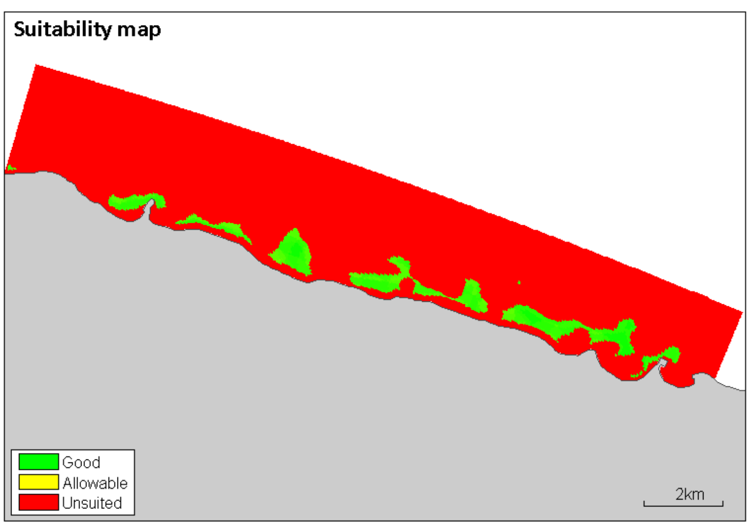
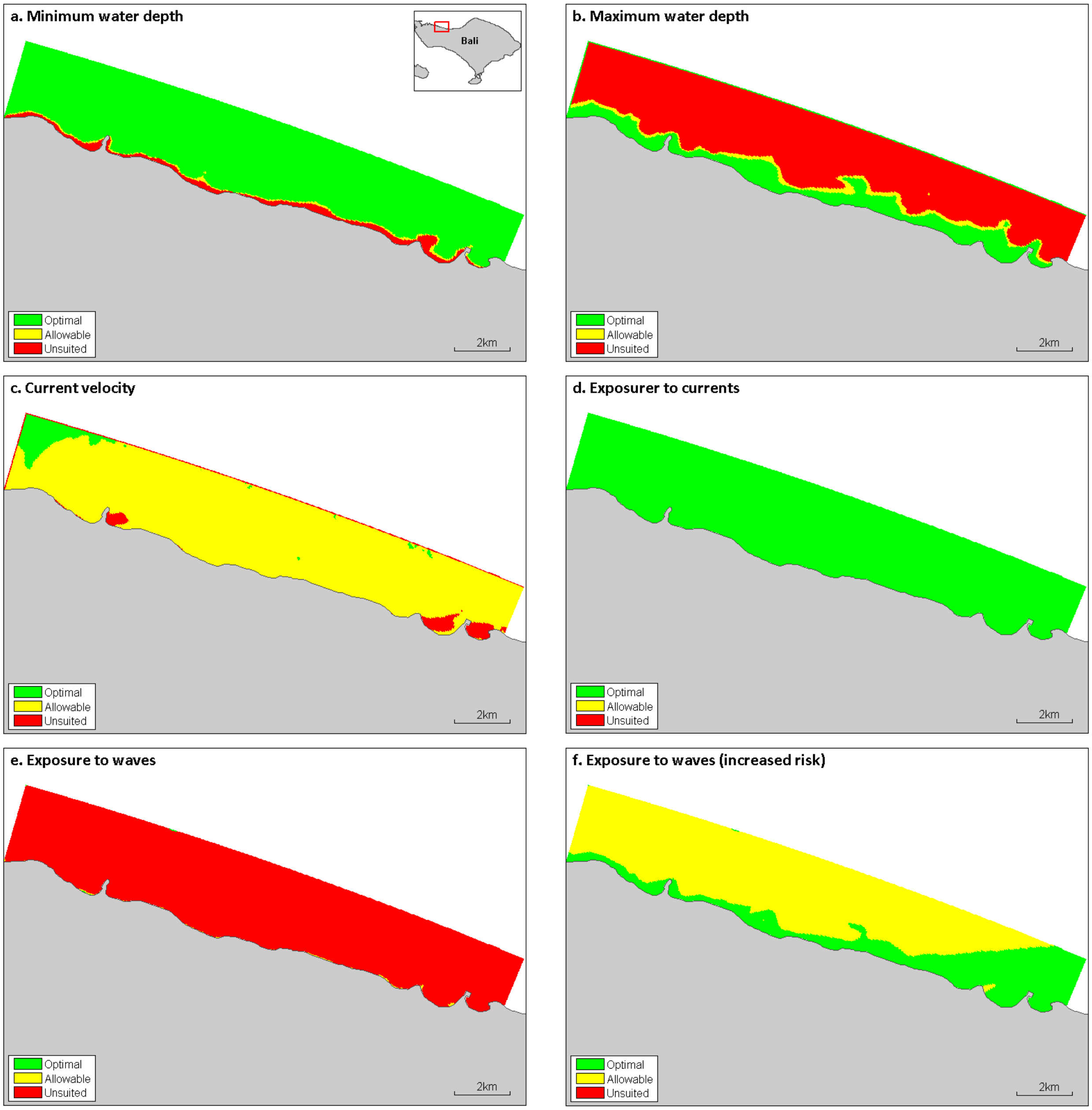


Figure 1.23: Suitability maps of the Celukanbawang area. Suitable areas were not found with a conservative consideration of wave risk. Reconsideration yielded the result as shown but incorporates a risk of wave that may reoccur every five years.



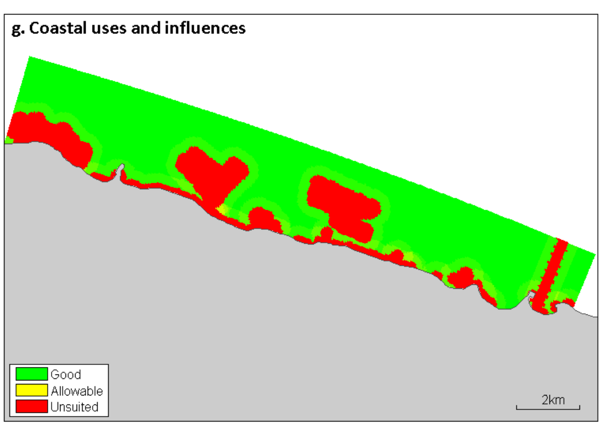


Figure 1.24: Suitability of the Celukanbawang area for: a. Minimum water depth, b. maximum water depth, current velocities (c + d) and waves (e + f). Suitability based on perimeter usage and presence of other influential anthropogenic and natural objects such as rivers and land based discharges (g).

Local carrying capacity based on particulate wastes

Local carrying capacities based on the release of particulate wastes in the form of faeces and waste feed were determined for a diet of 100 % trash fish and 70% trash fish – 30 % pellets. Deposition thresholds of 1, 1.5 and 5 g C m^2 d^{-1} were used. Maximum farm sizes were found to be in the order of 7 to 81 t a^{-1} for a diet of only trash fish but increased significantly with a combination of trash fish and formulated feed to production rates of 11.5 to 192 t a^{-1}.

Regional carrying capacity based on dissolved nitrogen fluxes

Flow rates into the total suitable areas were quantified to be in the order of 3.6 x 10^8 m^3 d^{-1} as an average of neap and spring tides. Total Dissolved Nitrogen background concentrations were in the order of 0.12 ± 0.037 mg N l^{-1}. The maximum allowable daily load was 247 ± 52.8 kg N d^{-1} for the entire domain, corresponding to carrying capacities of 2230 ± 332 t a^{-1} for a diet of only trash fish and 2439 ± 717 t a^{-1} for a diet of trash fish and pellets.

Total carrying capacity and farm arrangement

The 403 ha of suitable area can hold between 86 and 110 farms as shown in table 1.8. The regional carrying capacity was only exceeded for scenarios with a deposition threshold of 5 g C m^{-2} d^{-1}. A selection of farms was made to remain below the regional carrying capacity as shown in figure 1.25. If only trash fish is used as feed, farm sizes are generally smaller allowing 38 farms in contrast to the use of partly formulated feeds which result in the placement of 15 larger farms.

Table 1.8. Local carrying capacities for proposed farms at different thresholds and diets.

Diet	Threshold	Minimum (t a^{-1})	Maximum (t a^{-1})	Farms	Total production (t a^{-1})
100 % trash fish	1 g C m^{-2} d^{-1}	1	7.5	100	359
	1.5 g C m^{-2} d^{-1}	1	12	102	609
	5 g C m^{-2} d^{-1}	5	81	94	3471
	5 g C m^{-2} d^{-1} (limitation)	21	81	36	2229
70 % trash fish	1 g C m^{-2} d^{-1}	0.5	11.5	110	595.5
30 % pellets	1.5 g C m^{-2} d^{-1}	1	21	107	1023
	5 g C m^{-2} d^{-1}	12.5	192	86	7567
	5 g C m^{-2} d^{-1} (limitation)	41	192	15	2438

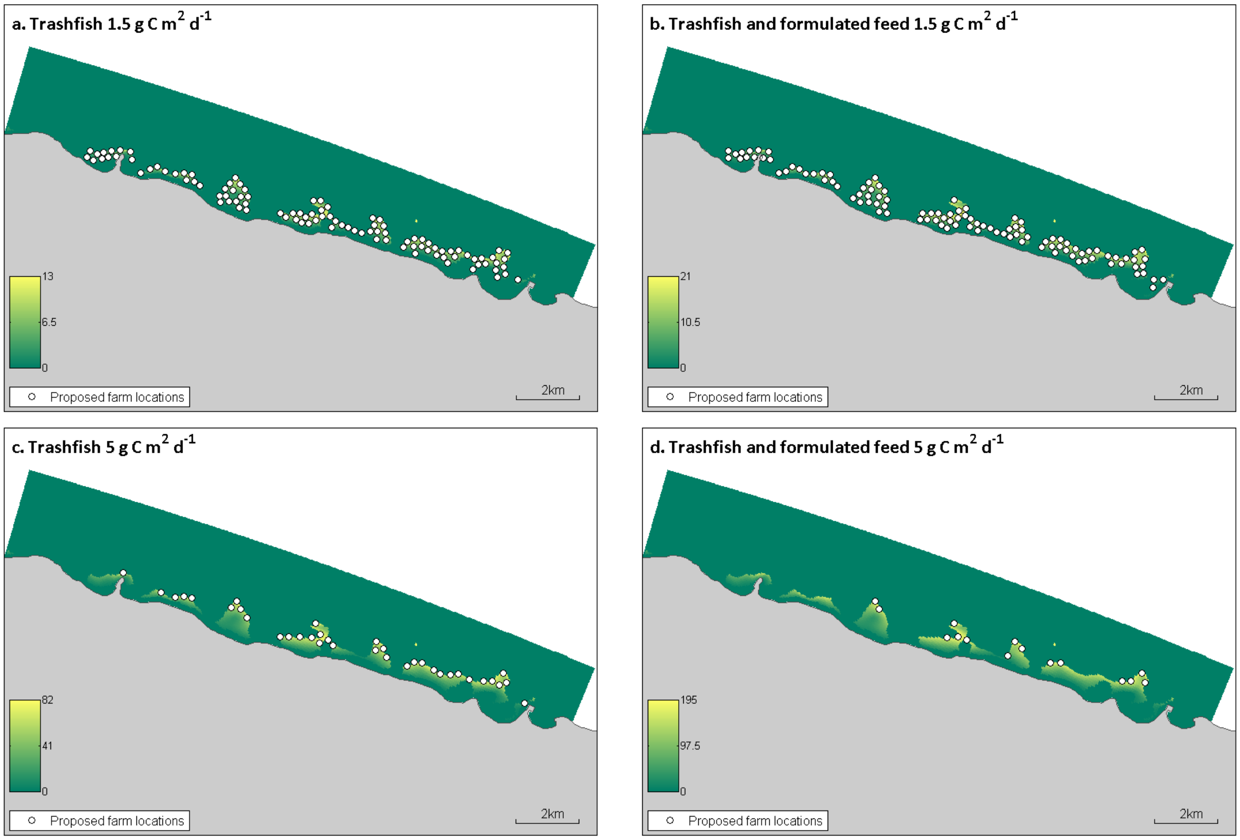


Figure 1.25: Carrying capacity maps exemplarily shown for thresholds of 1.5 and 5 g C m^2 d^{-1} based on diet composition of 100 % trash fish (a and c) and 70% trash fish and 30% formulated feed (b and d) with a limitation of the total carrying capacity based on nitrogen fluxes. Limited farm arrangement yield 36 and 15 farms for the two different diets, respectively.

1.4.3 Application of the Decision Support System to Saleh

Hydrodynamic model

The hydrodynamic model was set up using two curvilinear grids with a horizontal resolution of 400 meters up to 60 meters for a selected part of central Saleh Bay as illustrated in figure 1.26. Bathymetric information from the GEBCO database was improved with nautical chart information for the shallow regions. Tidal astronomical constituents were used to drive the model at the northern boundary inducing water level fluctuations onto the domain. The model reproduced water levels within the Bay with a mean error of 0.05 m when compared to measurements (Figure 1.27).

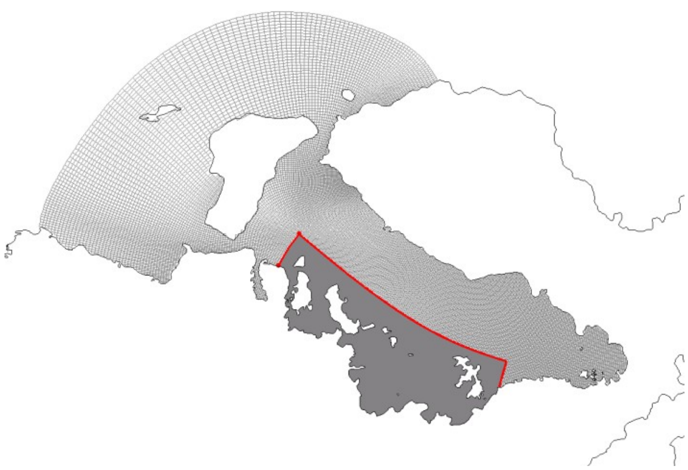


Figure 1.26: Saleh Bay hydrodynamic model grids. Each grid increases in resolution providing a 50 m cell size in the area of interest.

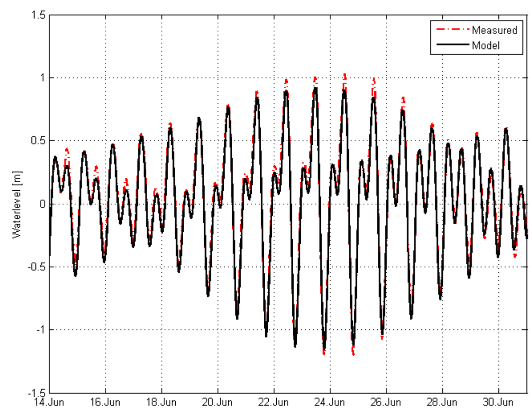


Figure 1.27. Comparison between measured and modeled water level measurements.

Wave model

A wave simulation was conducted for a worst case scenario where waves with a height of 3.4 meters were imposed at the northern model boundary. This wave height is based on a reading from the nomogram for deep water significant wave predictions (US Army Corps of Engineers 1984) for a wind speed of 9.9 m s^{-1} (6 hours) from north-north western direction. According to the NCEP reanalysis data set such event occurred once over the last 50 year period. Much of the imposed wave conditions dissipated because of the barrier island at the entrance of the bay. According to the wave simulation, the fetch length of the bay contributed to the development of wind generated waves within the bay.

Field measurements and surveying

Water quality samples, taken along two transects within the bay in June 2009, were analyzed for ammonium, nitrite, nitrate, phosphorus and suspended solids. Additionally salinity and dissolved oxygen were measured. Coastal uses and influences that were of any importance for the DSS were identified from satellite imagery and by survey.

Site selection

Overall suitability resulted in an area of ~26500 ha available for the development of potential floating net cages (Figure 1.28). Most of the unsuited area was identified based on depths. Exposure to waves also contributed to the elimination of suitable area. Current velocities were relatively low when compared to the adopted criteria. Confined bays showed very little water movement and were classified to be unsuited (Figure 1.29). Water quality observations fell within the range of the suitability criteria (Table 1.9). Coastal uses only contributed to a minimal elimination of suitable area close to the shoreline.

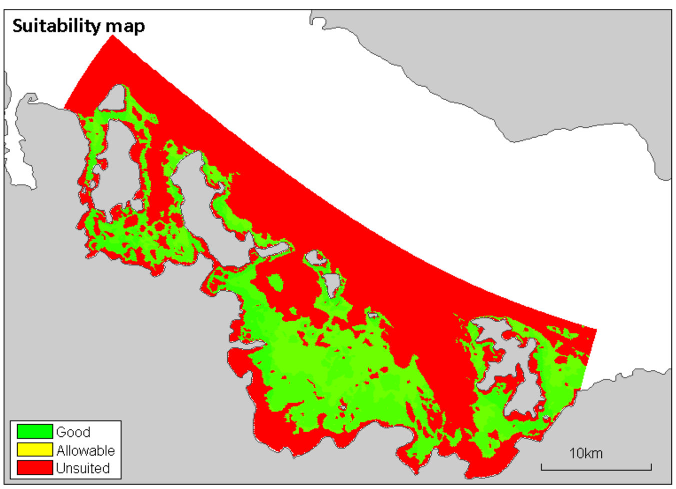


Figure 1.28: Suitability map for Saleh Bay. 26500 hectares is available for the development of floating net cages based on adopted criteria and used information.

Table 1.9. Observed water quality adopted for the suitability analysis for Saleh Bay.

Parameter		Mean ± std	n-samples	Suitability score
NH_4	mg N l^{-1}	0.0033 ± 0.0024	15	Optimal
NO_2	mg N l^{-1}	0.00046 ± 0.00047	10	Optimal
NO_3	mg N l^{-1}	0.0022 ± 0.0045	15	Optimal
PO_4	mg P l^{-1}	0.0023 ± 0.0014	15	Optimal
TSS	mg l^{-1}	1.35 ± 0.36	11	Optimal
Oxygen	mg l^{-1}	6.8 ± 0.07	8	Optimal
Salinity	ppt	31 ± 0.12	10	Allowable
T	°C	29.9 ± 0.3	5	Optimal

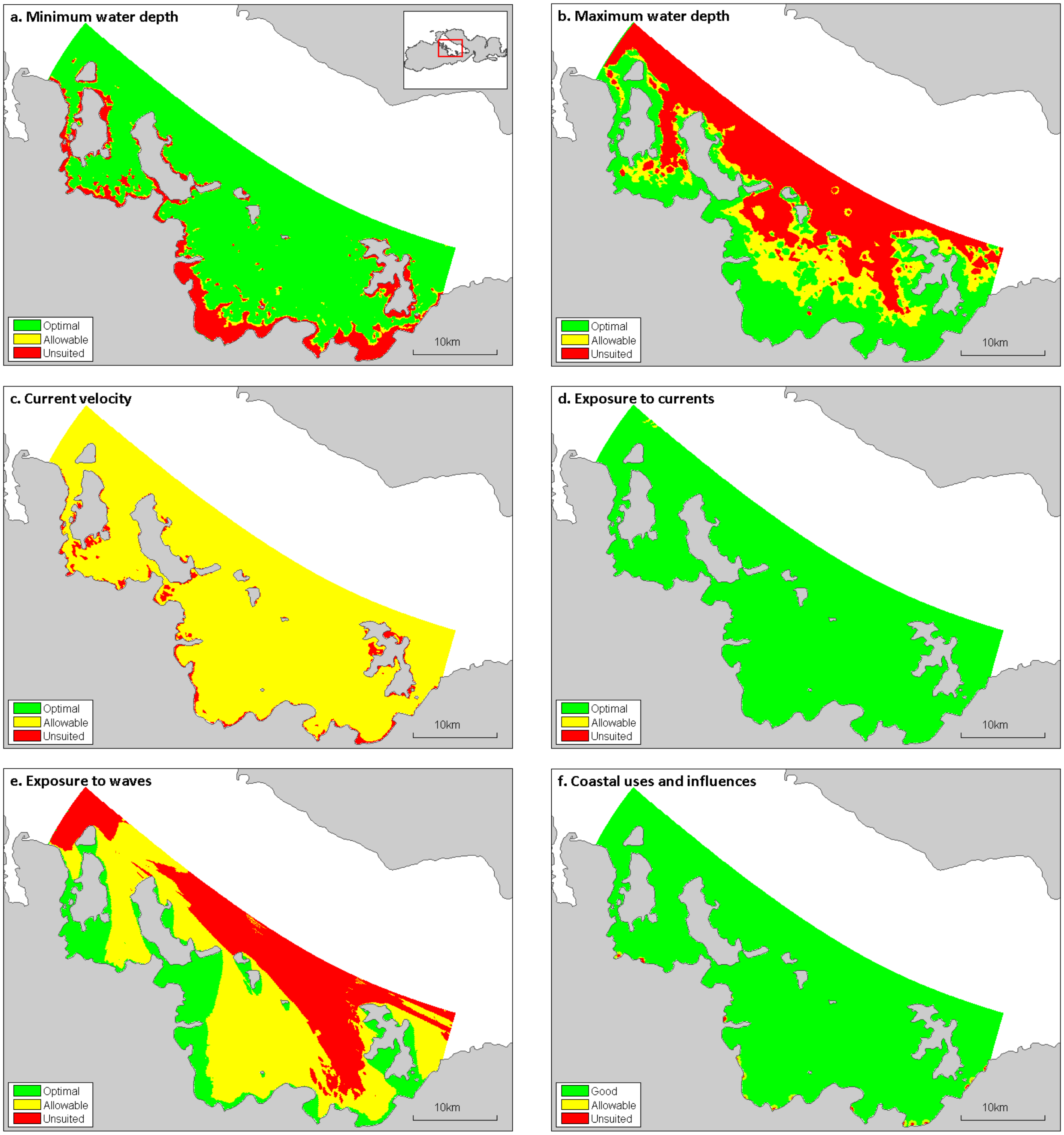


Figure 1.29. Suitability for each physical parameter: Minimum water depth, maximum water depth, current velocities and waves. Suitability based on perimeter usage and presence of other influential anthropogenic and natural objects such as rivers and land based discharges.

Local carrying capacity based on particulate wastes

Local carrying capacities based on the release of particulate wastes were determined for a diet of 100% trash fish and 70% trash fish – 30% pellets. Deposition thresholds of 1, 1.5 and 5 g C m^2 d^{-1} were used. Maximum farm sizes were found to be in the order of 24 to 275 t a^{-1} for a diet of only trash fish but increased significantly with a combination of trash fish and formulated feed to production rates of 37 to 651.5 t a^{-1}. High carrying capacities were limited to a small share of the total available space. The vast area holds lower carrying capacities as exemplarily shown in figure 1.30.

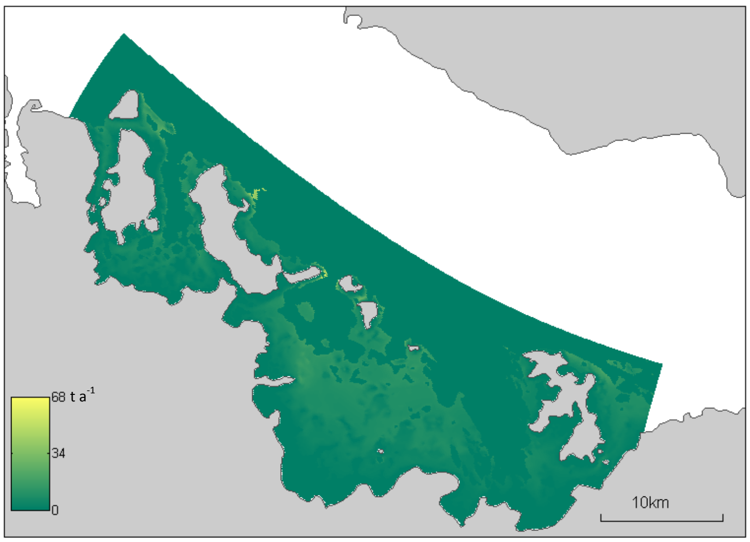


Figure 1.30: Local carrying capacity map of Saleh Bay exemplarily shown for a threshold of 1.5 g C m^2 d^{-1} based on diet composition of 70% trash fish and 30% formulated feed in farms with cages of 3x3x3 m and a stocking density of 10 kg m^{-3}.

Regional carrying capacity based on dissolved nitrogen fluxes

Flow rates into the total suitable areas were quantified to be in the order of 3.1 x 10^9 m^3 d^{-1} as an average of neap and spring tides. Total Dissolved Nitrogen background concentrations were observed to be in the order of 0.068 ± 0.014 mg N l^{-1}. The maximum allowable daily load was 2125 ± 454 kg N d^{-1} for the entire domain, corresponding to a regional carrying capacity of 10615 ± 2267 t a^{-1} for a diet of only trash fish and 11610 ± 2479 t a^{-1} for a diet of trash fish and pellets.

Total carrying capacity and farm arrangement

Because of the large area that is available for the development of floating net cage mariculture, the DSS was applied to identify the best locations for a limited number of farms. At first a selection was made for 100 farms based on the local carrying capacity only striving for the largest farms within the suitable area. Second, farm locations can be identified on the highest suitability score. The largest farm locations were found at the northern edge of the suitable areas where water depth and current velocities are highest. With a deposition threshold of 5 g C m^2 d^{-1}, limits were quickly reached based on the maximum allowable daily nitrogen load, limiting the number of farms from 100 to 38 (Table 1.10 and Figure 1.31).

Table 1.10. Carrying capacities for different thresholds and diets.

Diet	Threshold	Minimum (t a^{-1})	Maximum (t a^{-1})	Farms	Total production (t a^{-1})
100 % trash fish	1 g C m^{-2} d^{-1}	6.5	24	100	963.5
	1.5 g C m^{-2} d^{-1}	11	41.5	100	1616
	5 g C m^{-2} d^{-1}	67.6	275	100	10375
70 % trash fish	1 g C m^{-2} d^{-1}	10	37	100	1467.5
30 % pellets	1.5 g C m^{-2} d^{-1}	17.5	67.5	100	2606.5
	5 g C m^{-2} d^{-1}	201.5	651.5	38	11544

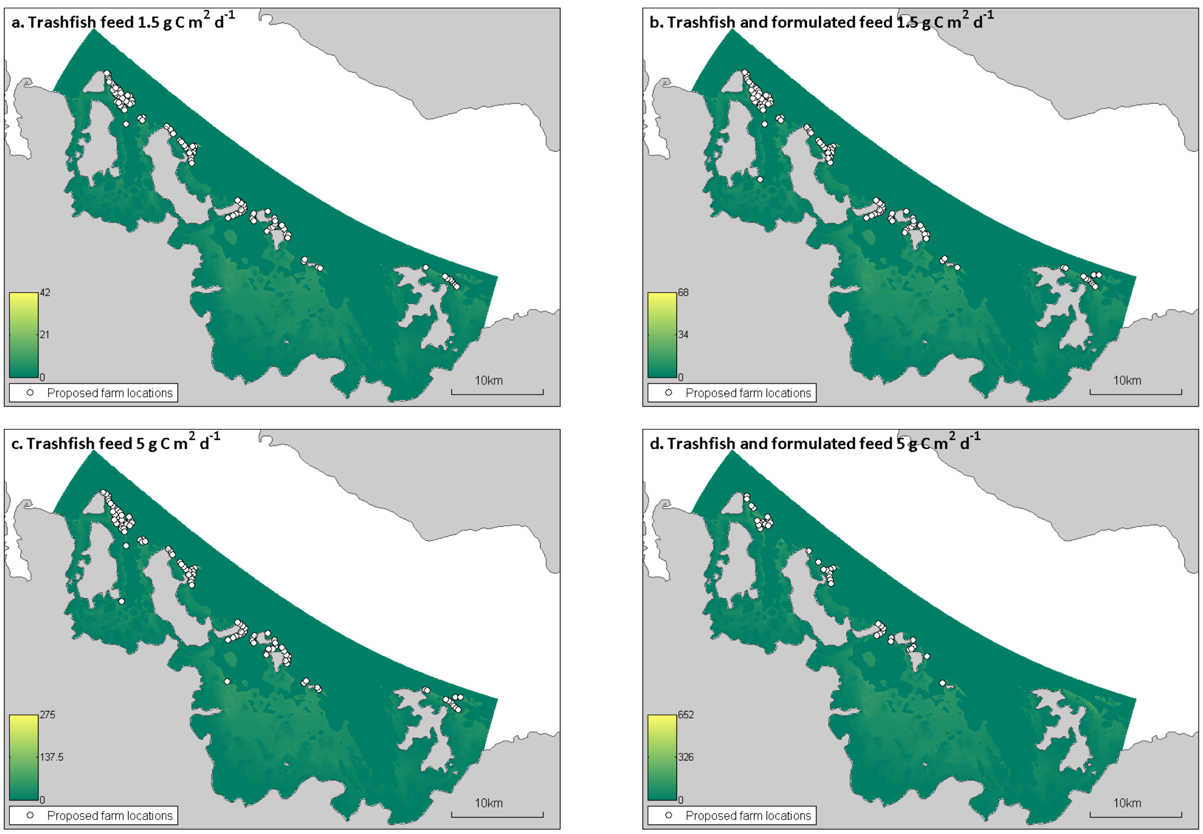


Figure 1.31: Carrying capacities exemplarily shown for a threshold of 1.5 and 5 g C m^2 d^{-1} based on diet composition of 100 % trash fish (a.) and 70% trash fish and 30% formulated feed (b.) with potential farm locations based on the highest carrying capacity.

Farm locations based on the suitability score show lower carrying capacities. Locations are more concentrated around the islands and southern shoreline (Table 1.11 and Figure 1.32). The total production rate of all farms is well below the regional carrying capacity and hence leaves further developing possibilities.

Table 1.11. Carrying capacities for different thresholds and diets.

Diet	Threshold	Minimum (t a^{-1})	Maximum (t a^{-1})	Farms	Total production (t a^{-1})
100 % trash fish	1 g C m^{-2} d^{-1}	2.5	16.5	100	340.5
	1.5 g C m^{-2} d^{-1}	4	28	100	593.5
	5 g C m^{-2} d^{-1}	26	186.5	100	3704
70 % trash fish	1 g C m^{-2} d^{-1}	3.5	25	100	542
30 % pellets	1.5 g C m^{-2} d^{-1}	7	45.5	100	975.5
	5 g C m^{-2} d^{-1}	61.5	441.5	100	8696.5

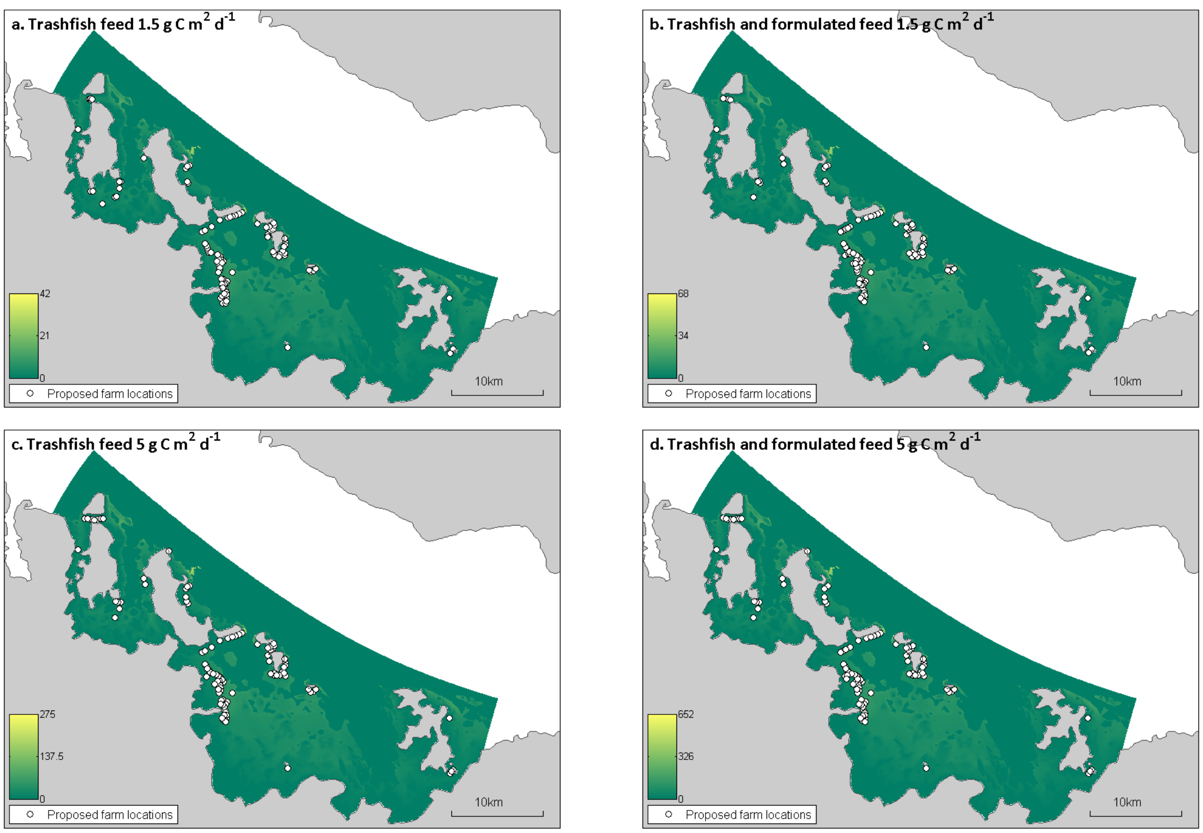


Figure 1.32: Carrying capacity exemplarily shown for a threshold of 1.5 and 5 g C m^2 d^{-1} based on diet composition of 100 % trash fish (a.) and 70% trash fish and 30% formulated feed (b.) with potential farm locations based on the best suitability.

1.5. General notes

The DSS provides an advanced understanding in the considerations to be taken for the sustainable development of floating net cage mariculture. Balancing suitability and carrying capacity reveal estimates of production potential over a larger domain. Application demonstrates the universal applicability of the DSS making it a useful tool for decision makers. A couple of side notes need to be made regarding the future use of the DSS.

Assumptions

Great effort is taken to incorporate feasible assumptions in the application as shown in section 1.4. Yet all production rates indicated by the DSS remain estimates. These estimates are strongly influenced by user input concerning suitability criteria, farm wastes, hydrodynamic information and deposition rates and will, to a certain degree, differ from reality.

Monitoring

The DSS as shown in this document incorporated the information as described and focuses on environmental sustainability. Exact farm placement should be considered on an individual basis. Selected sites should be monitored prior and during farm operation to safeguard productions.

Thresholds

A range of threshold is used to demonstrate the sensitivity of the DSS. Assimilative capacities lie within this range according to documented studies but may differ from place to place, even within one domain. The outcome of the DSS therefore provided a good reference of farm potential but should be considered with care.

Sustainability, production rates and best practice

Sustainable farm practice is considered within the selected region and does not contribute to the discussions on an inter-regional and global scale. Culture practice as considered by the DSS addressed current practices and technology. Technological advances and farmer skill always forms the basis for sustainable practice and can be incorporated into the DSS.

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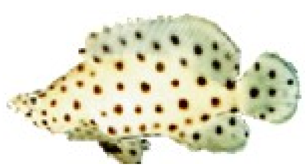
2. Grouper fingerling production and the potential of recirculation hatchery technologies in Indonesia

2.1. Introduction

A priority requirement for grouper net cage mariculture in Indonesia is the availability of fingerlings as initial stocking for the grow-out to marketable fish size. The term fingerling in the local market in Indonesia is used for juvenile fish sizes of about 7 to 10 cm. These are reared from smaller seed of 3 to 4 cm in length which is in turn cultivated from fertilized eggs deriving from a broodstock. Business components of grouper culture thus include the marketing of brooders, eggs, seed and fingerlings.

Technology of grouper seed production was begun in 1990 and started with the species of mouse grouper, *Chromileptes altivelis,* the most expensive species among the groupers. Nowadays, similar techniques are used for five other grouper species; tiger grouper (*Epinephelus fuscoguttatus*), orange spotted grouper (*Epinephelus coioides*), marble grouper (*Epinephelus microdon*), coral grouper (*Epinephelus corallicola*) and coral trout (*Plectropomus leopardus*) (Fig. 2.1). Seeds of those species have already been successfully produced in mass production scale, although in many cases they have a low survival rate and inconsistent production.

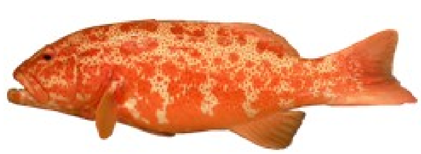


Barramundi cod, mouse grouper*, Chromileptes altivelis*

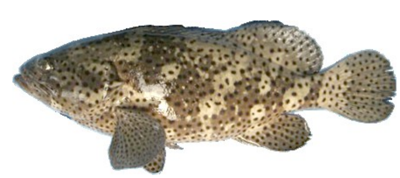
Tiger grouper*, Epinephelus fuscoguttatus*

Marbled grouper*, Epinephelus microdon*

Orange spotted grouper*, Epinephelus coioides*



Coral trout*, Plectropomus leopardus*



Rockcod grouper*, Epinephelus corallicola*

Fig. 2.1: Commercial Grouper species in Indonesia

Grouper seed production in Indonesia is usually done in traditional hatcheries which are based on a flow through system without applying any water re-use. There are two types of traditional hatcheries in Indonesia, the so-called Complete Hatchery (CH) and the Small Scale Hatchery (SSH), the latter of which is commonly operated by a family. The CH is generally bigger in scale of business, has more facilities and its own brood stock for egg production. By contrast, in a SSH only eggs already fertilized which are usually bought from a Complete Hatchery are hatched. About 80 % of Indonesian seed production is still performed in SSH. It typically consists of a unit of sand filter tanks, four larvae tanks of around $4.0 \cdot 4.0 \cdot 0.8$ m in size, two rotifer tanks and four plankton tanks for the culture of microalgae (usually *Nannochloropsis*). Small Scale Hatcheries prefer to sell the seed already at a size of 3 to 4 cm instead of continuing the rearing up to fingerling size in order to have an instant income and less production risk considering the short period of rearing (45 days vs. 2 to 3 months). Instead, cultivation of the juveniles up to fingerling size is mostly done by specialized farms located in East Java and North Sumatra using the traditional outdoor technology in brackish water ponds (Fig. 2.2 a). By contrast, a few hatcheries in Bali are producing fingerlings in indoor cultures (Fig. 2.2 b). It may also occur that grow-out farmers rear grouper fingerlings from smaller seed by their own in floating net cages (Fig. 2.2 c). However, this kind of fingerling production is restricted to a few cases only and to sites with a good protection from wave action and strong currents.

Fig. 2.2: Systems for Grouper fingerling production (a) using nets in brackish water ponds, (b) indoor system, (c) in floating net cages

Despite the high demand for grouper fingerlings the production is still limited, which is mainly due to the following reasons: (1) high investment, particularly to buy the seed of 3 to 4 cm; (2) the longer cultivation period needed to produce fingerlings; (3) high risks due to diseases or environmental impacts during the culture period. A failed production cycle constitutes a big financial loss for the farmer. Morphological deformity is often observed in fingerlings ranging from 5 to 25 % for each batch of production. Fingerlings with abnormalities are not marketable and they are usually discarded. By contrast, in the small seed sizes, the abnormalities are more difficult to notice. The reasons leading to the deformations are still poorly understood. Among the factors currently discussed are mal nutrition, environmental impacts and genetic disorders.

2.2. State-of art in the traditional technology of Grouper seed and fingerling production

Seed production (3-4 cm)

Fertilized eggs are collected from the broodstock tank (only floating eggs are fertilized) and directly transferred to larval rearing tanks. Egg handling must be done very carefully in order to avoid any mechanical shock. The stocking density of the eggs ranges from 5,000 – 10,000 ind./m^3. The suitable size of larvae rearing tanks is approximately 10 m^3 (with a depth of 1 m) in volume to produce around 10,000 juveniles. Both round and rectangular shaped tanks are used. When using a rectangular shaped tank, the four corners of the tank should be rounded in order to avoid larval aggregations in the corners. Tanks are usually equipped with an aeration system and a sand filtration system as shown in Figure 2.3. At a temperature of 28-29°C the eggs normally hatch around 20 hours after fertilization.

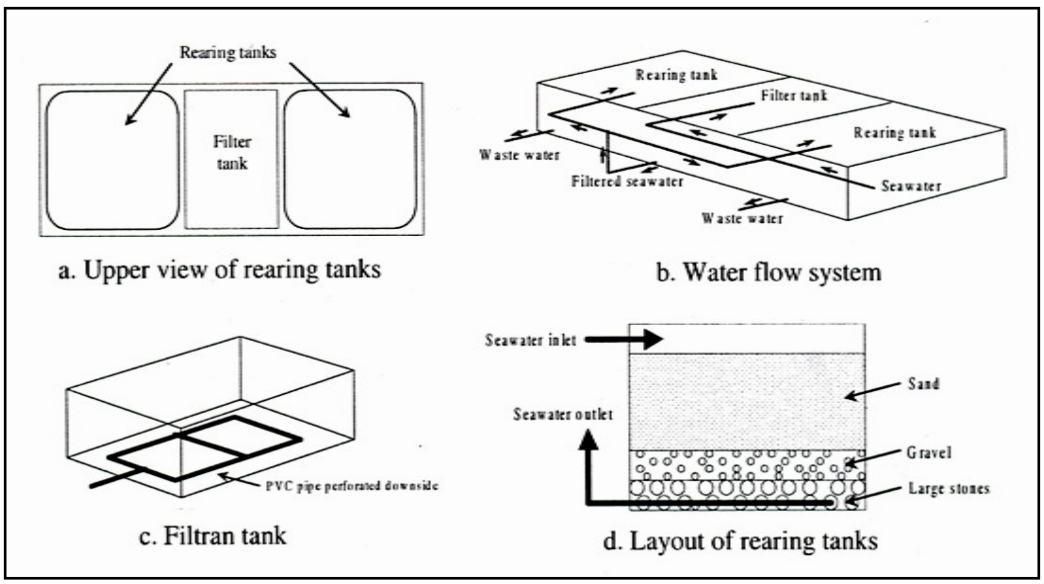


Fig. 2.3: Layout of larvae rearing tanks (Sugama et al., 2001)

The mass mortality due to larvae aggregation is minimized by an adequate aeration intensity. Between days 0 to 2 aeration needs to be rather strong to prevent eggs or larvae from sinking to the tank bottom. Between day 3 to 10 the intensity of the aeration is reduced to a gentle level but increased again at day 11 to 25. After day 25, when larvae start swimming in schools, rather strong aerations is provided to supply enough oxygen for the metabolic demands.

Light intensity and photo period are important factors for larvae feeding. At the initial stage of rearing the light intensity should not fall below 1,000 to 1,500 lux and last at least for 10 hours during 10 days. After 12 days the light intensity may be reduced to 600 - 1,000 lux.

Feeding consists of rotifers enriched with PUFAs and vitamines, artificial diet and Artemia. There are two different size types of rotifers: the SS-type rotifers (120 to 140 mm in lorica length) and the larger S-type rotifers (180 to 200 mm in lorica length). SS-type rotifers are given at day 3 when the larvae's mouths open at a maintenance density of around 5 rotifers per ml of rearing water. The rotifer diet is provided until day 30. Before supplying the rotifers to the rearing tank, *Nannochloropsis* is added to the culture together with enrichment factors (Aquarian Plus) at a dose of 10 g per tank.

Artificial microdiets of sufficient nutritional value (e.g. Love Larva, Hayashikane Sangyo Ltd., Shimonoseki, Japan) are given in combination with rotifers around day 17 when larvae get large and strong enough for water exchange. Artemia is given in combination 3 to 4 days after introducing the artificial diet, thus, around day 20 for a period of 30 days (Tab. 2.1). The juveniles harvested from the rearing tank are constantly graded into classes of equal size by hand to prevent from cannibalism upon cultivation.

Table 2.1: Feeding regime for seed production (3-4 cm)

Type of Feed	**Feeding Period**
Rotifers	Day 5 to day 29 in the morning and afternoon
Love Larva No. 02	Day 17 to day 31
03	Day 28 to day 39
04	Day 36 to day 44
Artemia	Day 30 to day 44 given at morning
	Day 20 to day 44 given at afternoon

Fingerling production (7-10 cm)

The adequate tank volume for juvenile rearing usually accounts for 5 to 10 m^3. The larvae rearing tanks including water supply and aeration system can thus be used for fingerling production. The stocking density is about 500 to 600 ind./m^3 of 3 to 4 cm in size in order to avoid stress and subsequent immuno-deficiency. As a result of the affected immuno-system the risk of diseases, especially of VNN (viral nervous necrosis), increases. A water exchange of about 500 % of the tank volume per day is applied. To avoid strong light intensity and maintain stable temperature blue or black canvas super net shading is commonly used. Water temperatures are kept at 27 to 28°C with salinities of 30 to 35 PSU.

For fingerling production some farmers practice a full pellet diet, but in most cases trash fish, or trash fish mixed with "tiny shrimp" (different crustacean species caught in shrimp ponds or in the wild) as life feed is used. It is a widespread opinion among farmers that feeding with trash fish and tiny shrimps will promote growth better than pellets, despite its disadvantages. The water quality is easily deteriorated, the continuous availability of trash fish is uncertain, and the quality is easily rotten without steady cooling or freezing. In addition, trash fish is suspected to be a vector for diseases, which also holds true for tiny shrimps, especially when they are collected from intensive shrimp ponds.

Commonly used commercial pellets are Otohime (e.g. Aquatic Enterprise Co., Japan) and NRD (Inve Asia Ltd., Thailand), although there are also other artificial diets in use such as Love Larva from days 45 to 50 on and squid oil (Riken Vitamin Co. Ltd., Tokyo, Japan) as lipid source.

2.3. Economic analysis of traditional hatchery operation in Indonesia

Based on interviews and on-site evaluation, the current costs of grouper seed and fingerling production have been estimated separately for a total production of 100,000 individuals. The financial analysis has been conducted in 2008. Currency is Indonesian Rupiah (IDR), with an annual average exchange rate in 2009 of 100,000 IDR equaling 6.91191 Euro. Total costs can be discriminated into costs of investment, fixed and variable costs. Investment and fixed costs encompass the purchase of land (1,000 m^3), the construction of buildings and tanks and the technical equipment. The area required for seed production is based on a common ratio of larvae-tank:rotifer-tank:plankton-tank of 1:1:4. Costs for consumables such as eggs resp. seed, feed, chemicals, energy, freshwater and maintenance (incl. spare parts) as well as wages and interests are considered as variable costs. Tables 2.2 and 2.3 summarize the investment, fixed and variable costs for seed production (3-4 cm) assuming a price of rural land of 200,000 IDR/m^2. It should be noted, however, that this price is strongly variable depending on the location. The same holds true with respect to labour. In many cases the technicians do not receive a salary but a percentage share of the profit gain of each crop cycle. However, in some cases the technician receives a fixed monthly salary or a minimum salary for his daily needs and a bonus when the production target is reached depending on the commitment with the hatchery owner.

Table 2.2: Fixed costs in seed production

Item	Investment (IDR)	Econ. age (year)	Fixed costs/yr (IDR)	Fixed costs per crop (IDR)
Land	**200,000,000**	10	20,000,000	**4,000,000**
Construction				
Sand filter (2x3x2 m)	6,000,000	5	1,200,000	240,000
Reservoir (2x3x2 m)	3,000,000	5	600,000	120,000
20 tanks for rotifer production (3x2x1.5 m)	50,000,000	5	10,000,000	2.000,000
12 tanks for plankton production (4x5x1.25 m)	60,000,000	5	12,000,000	2.400,000
20 tanks for larvae rearing (3x3x1 m)	50,000,000	5	10,000,000	2.000,000
Subtotal	**169,000,000**			**6,760,000**
Equipment				
2 water pumps (centrifugal 2")	6,000,000	3	2,000,000	400,000
2 water pumps submersible	2,000,000	3	670,000	135,000
2 aeration/blower units	5,000,000	3	1,650,000	330,000
Power supply (generator, circuits)	8,000,000	5	1,600,000	320,000
Sea water installation	3,500,000	5	700,000	140,000
Fresh water installation	2,500,000	5	500,000	100,000
Plastic containers, fiber glass for rotifer, plankton net, scope net, etc.	1,000,000	2	500,000	100,000
Subtotal	**28,000,000**			**1,525,000**
Buildings				
Storage	7,500,000	5	1,500,000	300,000
Generator house and workshop	7,500,000	5	1,500,000	300,000
2 technician rooms with sanitary equipment	37,500,000	5	7,500,000	1,500,000
Subtotal	**52,500,000**			**2,100,000**
Total	**449,500,000**			**14,385,000**

Table 2.3: Variable costs in seed production

Item	Quantity	Unit	Unit costs (IDR)	Total costs (IDR)
Eggs (Tiger Grouper)	1,000,000	Pc	2	2,000,000
Feed				
Pellet	69	kg	100,000	6,900,000
Artemia	48	Can	300,000	14,000,000
Fertilizer				
Urea*	1	50 kg	80,000	80,000
TSP*	1	10 kg	1,700	17,000
ZA*	1	50 kg	75,000	75,000
FeCl	1	Package	1,500,000	1,500,000
Chemicals				
Elbajo	5	Small bag	150,000	750,000
Hypochlorite	2	50 Liter	100,000	200,000
Power supply	2	Month	1,000,000	2,000,000
Fresh water supply	2	Month	200,000	400,000
Tank and equipment maintenance	1	Package	1,000,000	1,000,000
Wages (technician salaries)	3 · 2	Month	1,000,000	6,000,000
Bank interest 12 %				53,940,000
	Total			**88,862,000**

*) Dosage: urea 60-80 ppm; TSP 20 ppm; ZA 10 ppm

A survival rate of 10 % is assumed from egg to seed of 3-4 cm in size. Apart from the interests for the capital required the feed constitutes the dominant cost factor. In sum, the following costs and profits yield from the production of a grouper seed crop of 100,000 individuals:

Total costs (fixed costs + variable costs)	IDR 103,247,000
Production value 100,000 items à IDR 1,200	IDR 120,000,000
Profit per season	IDR 16,753,000

For the indoor production of fingerlings (7-10 cm) from seed of 3-4 cm in size there is no need for rotifer and plankton tanks but a larger rearing space is required. Main expenses (i.e. 132,000,000 IDR) are for the purchase of seed. Assuming a survival rate of seed to fingerlings of 87 % and a market price of 4,000 IDR/individual the costs and profits of fingerling production (100,000 items) with either trash fish and tiny shrimp or pellet feeding are summarized in table 2.4.

Table 2.4: Comparison of costs (IDR) and profit of seed and fingerling production

Component	**Seed prod.**	**Fingerling prod. + pellet diet**	**Fingerling prod. trash fish + tiny shrimp**
Investment	449,500,000	389,500,000	389,500,000
Fixed cost	14,385,000	17,307,000	17,307,000
Variable cost	88,862,000	220,140,000	223,640,000
Total cost	103,247,000	237,447,000	240,947,000
Production value	120,000,000	400,000,000	400,000,000
Profit per season	16,753,000	162,553,000	159,053,000
Period per season (days)	45-50	65-75	55-65

In addition to the expenses listed above, transport costs have to be accounted for, since the sites for grow-out to marketable fish weight (> 500 g) in floating net cages are usually remote from the sites of fingerling production. Transportation of seed and fingerlings takes place in closed systems (ice cooled plastic bags in Styrofoam boxes) by means of small trucks for local distribution and airfreight for national and international shipment. Transport by sea is for regional shipment, e.g. from Bali to Java or Lombok. PCR for virus analysis at the harbour quarantine offices and the airports in Denpasar, Surabaya and Jakarta is a prerequisite for export and also for the domestic market.

2.4. Market demand for Grouper fingerlings in Indonesia

The actual and future market demand of grouper seed and fingerlings was estimated based on data collected through interviews of farmers and expert judgment and from data of the Directorate General of Aquaculture in Jakarta. There are three main regions of seed production in Indonesia, i.e. the Buleleng region in Bali, which accounts for about 70 % of the total grouper seed market, the Situbondo region in East Java and Lampung in South Sumatera. Around 95 % of grouper seed is made up by Tiger grouper (*Epinephelus fuscoguttatus)*, the remaining 5 % were Humpback grouper (*Chromileptes altivelis*) and Coral trout (*Epinephelus leopardus*). Grouper seed production and particularly of Tiger grouper significantly increased since 2004 as it can be traced by the development of larval rearing tanks in Bali (Figure 2.4).

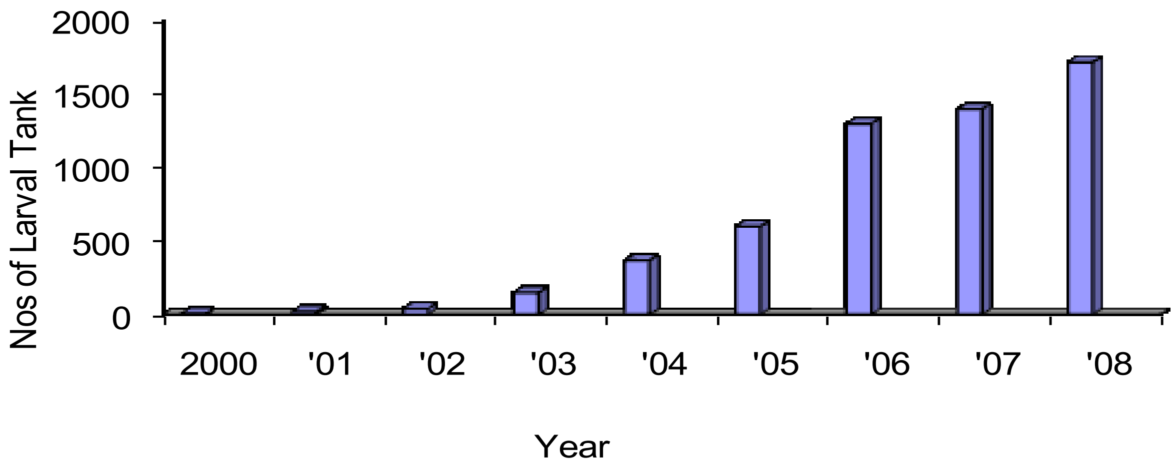


Fig. 2.4: Development of larval rearing tanks in Bali (pers. comm. GRIM, 2008)

Grouper seed for the domestic market is distributed to NTB, Lampung, Riau Archipelago, Batam, South Sulawesi, Southeast Sulawesi, Gorontalo and North Sulawesi. Grouper seed for export is mainly delivered to Singapore, Vietnam, Malaysia, Taiwan, Philippine, Japan etc. The present status of grouper seed production can be estimated from data of the main quarantine offices (Tab. 2.5), which are the official registration offices for all kinds of shipment. It can be traced from this table that in 2006 total seed production accounted for around 14,000,000 individuals and that the export market range in the same order as the domestic market.

Table 2.5: Grouper seed market (ind.) in Indonesia in 2006

Quarantine Office	Domestic	Export	Total	Monthly average
Denpasar	4,479,508	5,948,590	10,428,098	869,008
Surabaya	2,946,417	670,730	3,617,147	301,429
Jakarta	111,780	52,765	164,545	13,712
Total	7,537,705	6,672,085	14,209,790	1,184,149

Data of marketable size production of cultured grouper since 2000 to 2007 (DGA, 2008) is given in Table 2.6. From the production data the number of fish can be estimated assuming that the weight of marketable fish is 500 g/ind. on an average. The number of fingerlings required for this production has been estimated applying a mean survival rate of 80 % over the entire grow-out period.

Table 2.6: Estimated fingerling demand based on national production of market size grouper

Year	Production (tons)	Number of fish (ind.)	Number of fingerlings (ind.)
2000	6,879	13,758,000	16,509,600
2001	3,818	7,636,000	9,163,200
2002	7,057	14,114,000	16,936,800
2003	8,865	17,730,000	21,276,000
2004	6,552	13,104,000	15,724,800
2005	6,088	12,176,000	14,611,200
2006	8,489	16,978,000	20,373,600
2007	8,035	16,070,000	19,284,000

From a comparison of tables 2.5 and 2.6 it appears that the number of fingerlings required as estimated from grouper production in 2007 is much higher than the amount produced for the domestic market. This means that the fingerlings not only derive from hatcheries but also from wild catch. In addition it has to be taken into account that the life grouper market in Indonesia is not entirely based on culture but also on wild catch. When the size of wild caught grouper is > 500 g it can be directly sold after acclimation, if the size is less the fish will be kept in culture and fed until reaching the marketable size of at least 500 g.

However, the projected demand of grouper seed in 2006 according to the national planning of grouper culture development in Indonesia by the Directorate General of Aquaculture (2006) is very close to the demand of fingerlings calculated on the basis of marketable grouper production (Tab. 2.7). By contrast, projected numbers of fingerlings required in 2007 are overestimated by 20 %.

Table 2.7: Projected demand of grouper seed, 2006 – 2009 (DGA, 2006).

Year	2005	2006	2007	2008	2009
Number ($\cdot 10^6$)	15	21	25	30	35

Data from the Directorate General of Aquaculture on the existing and planned area used for fish mariculture as shown in Table 2.8 can be used to estimate the future demand of fingerlings required for grow-out.

Table 2.8: Existing and projected areas for mariculture development by province, 2005-2009 (DGA 2006)

Province	**Potential area (ha)**	**Existing grow-out area for marine fish species (ha)**					
		2004	2005	2006	2007	2008	2009
NAD	126.96	1.12	1.3	1.3	2.5	2.5	3.8
North Sumatera	179.55	3.9	5.4	7.2	9.0	9.0	18.0
Riau	105.92	3.9	10.6	10.6	10.6	10.6	10.6
KEPRI	91.76	10.1	8.3	9.2	9.2	9.2	9.2
Jambi	0	0	0	0	0	0	0
West Sumatera	35	0.57	2.9	3.5	3.5	5.3	5.3
Bengkulu	0	0	0	0	0	0	0
South Sumatera	0	0	0	0	0	0	0
Bangka Belitung	17.51	1.38	0.9	0.9	0.8	1.3	1.8
Lampung	39	3.07	3.9	3.9	3.9	4.3	4.3
Banten	85	6.95	6.6	6.8	8.5	8.5	5.1
DKI Jakarta	4	2.07	0.1	0.1	0.1	0.2	0.2
West Java	0	0	0	0	0	0	0
Central Java	11	0.12	0.7	0.7	0.7	0.7	0.7
DI-Yogyakarta	0	0	0	0	0	0	0
East Java	71	6.69	5.0	5.0	5.0	3.6	3.2
Bali	11	0.74	0.3	0.4	0.7	1.1	1.1
NTB	303	4.72	21.2	22.4	24.2	24.2	24.2
NTT	151	0.46	4.5	5.6	6.0	6.0	7.6
West Kalimantan	3873	0.29	298.2	309.8	309.8	309.8	309.8
Central Kalimantan	0	0	0	0	0	0	0
South Kalimantan	15.88	0.02	0.6	0.6	0.6	0.6	0.6
East Kalimantan	322.32	0.95	15.1	16.1	19.3	22.6	22.6
North Sulawesi	315	0	15.8	15.8	18.9	22.1	22.1

Table 2.8: Continued

Gorontalo	39	0.91	2.0	2.0	2.2	2.3	2.3
Central Sulawesi	593	1.13	22.5	23.7	23.7	23.7	23.7
South Sulawesi	20	0	1.2	1.2	1.2	1.2	1.2
South East Sulawesi	452	4.26	22.6	22.6	27.1	27.1	31.6
Maluku	222	1.36	6.7	9.8	15.5	15.5	17.8
North Maluku	133	1.21	4.0	4.0	9.3	9.3	12.0
West Irian	827	0.11	24.8	24.8	33.1	41.4	41.4
Central Papua	72	0	2.9	2.9	2.9	2.9	2.9
East Papua	2	0	0.2	0.2	0.2	0.4	0.4
TOTAL	8117.9	56.03	488.3	511.1	548.5	565.4	583.5

As an example the total effective area for floating net cages and penculture in 2007 is 548.5 hectares which are spread over different provinces in Indonesia. According to data from DGA (2006) the productivity of fish accounts for about 2,500 kg per 65 m^2. Assuming a survival rate of 90 % this equals a need of about 5,500 fingerlings. It follows that the total number of fingerling required for grow-out in an area of 548.5 ha will be more than 450,000,000 individuals which is much higher than the present status of grouper fingerling production. This is certainly due to the fact that the area licensed for mariculture is not entirely suited and used for fish farming and that only a small fraction of the mariculture activities in these areas is devoted to grouper rearing.

Considering the master plan for future aquaculture development of the DGA, which aims at an upscaling especially of grouper mariculture in order to enhance local welfare of the coastal population, as well as the introduction of new farming technologies, such as the implementation of large sized floating cages owing a diameter of > 10 m and an effective depth of 5 m, the domestic demand of grouper fingerlings will further increase. Recently, also the implementation of submerged cages has been considered. The stocking requirements for these types of cages is quite high, amounting to more than 200,000 fingerlings per cage.

Benchmark: Recirculation System Hatcheries

The development of recirculation system hatcheries (RSH) for fish rearing began more than 35 years ago, but a successful production was limited to some sub- tropical species only. Countries like Denmark, Norway, Japan, USA, United Kingdom and Australia are using these RSH for experimental as well as for commercial purposes. But only several common species such as eels, carp, seabream and salmon can be produced commercially at present. As a consequence, the use of such systems in tropical countries is very limited and is furthermore considered as a very expensive technology which has not completely been proven suitable for tropical fish species yet. Therefore, there is a necessity for modifications of the existing recirculation technology to adapt it to the tropical environmental conditions.

So far, the experience with recirculation system technology for grouper seed production in Indonesia revealed that not all parts or components of the applied technology are needed for a tropical country such as the chillers and the recirculation system for larvae rearing. The plankton production and the harvesting system did not perform well and has been operated manually. Some small but crucial spare parts could not be obtained domestically, thus, the procurement was time-consuming, expensive and the guarantee process complicated. Due to the fast physiological reaction time and booming bacteria development under tropical conditions the water quality dropped drastically during the production process. Tests with a variety of tropical species such as different grouper species, snapper and milkfish revealed that the technology applied is suitable for species that are active, pelagic and able to be stocked in high densities, which is not the case for grouper. Unfortunately, these species are the ones having relatively low market value such as milkfish and mangrove snapper. Compared to the production target for grouper species according to the technical specification (> 30 kg/m^3), the density and survival rate was still relatively low (< 4 kg/m^3). Similar problems are reported from test runs of a RSH in Malaysia.

As a consequence of this experience, a hybrid technology should be developed, which takes into account the climatic and infrastructural conditions in Indonesia and the limited budget of potential operators. This hybrid hatchery system would integrate both components of the traditional hatchery technology as well as of a recirculating system. The basic technical concept should address the following aspects:

In order to reduce energy consumption and risks of technical failure the system should use a natural gravity flow , i.e. tanks should be installed on different levels in order to reduce pump action.

Temperature stability is an important prerequisite for seed production. However, due to the largely constant seasonal temperature conditions in Indonesia, relatively stable temperature conditions can be achieved without a cost-intensive thermal regulation system simply by recirculation, filtering and aerating the water. For phytoplankton cultivation, natural daylight instead of artificial illumination should be used.

In order to assure a good water quality, the saltwater source should be from the deep water with a sand or dead coral substrate. In general, deep water is characterized by more stable temperature and salinity conditions and is less subjected to pollution and pathogens. For water purification natural biofilters (e.g. macroalgae beds such as *Ulva*) may be applied as nutrient strippers and sedimentation chambers. Due to the tropical temperature conditions the macroalgae can be cultivated year-round. Apart from skimmers, cyclones and sedimentation tanks, ceramic filters and a UV-treatment should be used for water treatment.

Bio-security is a key factor in the production process. Effective bio-security protocols should be established. The different modules of the system, i.e. broodstock tank, larval rearing and ongrowing tanks should ideally have separate water circulation systems in order to avoid a chain of infection.

To get an impression of how an efficient recirculation system could work and to present a best-practice example, the following paragraph describes an environmentally responsible aquaculture recirculation system from Cell Aquaculture (CAQ). CAQ has just inked a memorandum of understanding with a Malaysian based multinational corporation to commence feasibility of establishing large scale land based multi-species aquaculture productions.

The system is designed to be used as a low cost modular system that can also be placed close to densely populated areas. It was first targeted for barramundi fingerlings and designed to handle stocking density of up to 75 kg/m³. This system - consisting of at least 16 modules - is expected to be capable of producing 66 tons/year of barramundi. The number of modules is matched to meet the required market demand resp. the financial resources of the producer and could easily be expanded.

Each modular system comprises:

- 2 · 10,000 liter tanks and 1 · 4,000 liter;
- a mechanical filter, which is a home-made belt filter fitted with a 63 µm screen;
- a moving bed reactor bio-filter;
- oxygen stone, supplied from oxygen generator, control manually (Ozone is used to maintain oxygen redox between 120-200 mV);
- 2 · 1 HP water pump.

The farm is designed to be run by 2-3 people, which is -compared to the traditional hatcheries- not very labour-intensive. In general, the production cycle consists of three periods with an overall length of five month. There is no special features for waste treatment other than collecting and trucking it away.

Bio-security is critical for success, hence, Cell Aquaculture developed a fully enclosed bio-security-system with an insulated and temperature controlled environment. The environment and strict operating protocols should minimise the introduction of contaminants to the system. As field experiences have shown, a loss of the entire stock threatens the livelihood of the hatcheries. In contrast to the traditional hatcheries, CAQ implemented a risk management to avoid such impacts. If by chance, a disease or a system failure occurs in a particular unit of the Cell Aquaculture system, it is quarantined to that unit only, without any further effect on the rest of the production system, which minimises the possibility of a complete system failure. A monitoring system immediately alerts operators to any matters requiring attention in the production process. According to Cell Aquaculture, the controllable environment also enables the hatchery to maintain low stress growing conditions, resulting in low mortalities leading to increased productivity.

2.5. References

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Integriertes System für das Management einer ökologisch und sozio-ökonomisch nachhaltigen Marikultur in Indonesien (Teilprojekt 1)

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16. Zusätzliche Angaben

Das Vorhaben wurde im Rahmen der 2. Phase des SPICE Programms (Science for the Protection of Indonesian Coastal Ecosystems) durchgeführt.

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18. Kurzfassung

Im Rahmen des SYSMAR-Projektes wurde ein integriertes Decision Support System (DSS) für einen nachhaltigen Ausbau der Fischzuchtaktivitäten in indonesischen Küstengewässern entwickelt. In dem System, welches auf einer Kombination von Felddaten, numerischen Simulationsmodellen und GIS-Databanken basiert, werden nutzungstrelevante Entscheidungskriterien zusammengeführt, um eine umweltverträgliche Entwicklung der Fischzucht zu gewährleisten. Das DSS gestattet eine optimierte Auswahl von Eignungsgebieten zur Ansiedlung von Fischfarmbetrieben und ermöglicht darüber hinaus eine gebietsspezifische Abschätzung der ökologischen Tragfähigkeit sowie der Wirtschaftlichkeit verschiedener Produktions- und Ausbauszenarien.

Zur Demonstration der Leistungsfähigkeit wurde das System auf zwei Gebiete in Nord-Bali und Sumbawa angewendet, die im Rahmen des Entwicklungsplans des indonesischen Ministeriums für marine Angelegenheiten und Fischerei für einen zukünftigen Ausbau der Fischzucht vorgesehen sind. Mit dem DSS und den aus der praktischen Anwendung resultierenden Empfehlungen wird den indonesischen Fachbehörden und der Marikulturwirtschaft eine wissenschaftlich begründete Leitlinie für ein nachhaltiges Management der Marikultur zur Verfügung gestellt.

Begleitend zu den Forschungsaktivitäten erfolgte eine Intensivierung des Capacity Building durch Trainingskurse in Indonesien und Deutschland sowie Ausbildung im Postgraduierten- und Doktorandenprogramm „Coastal Geosciences and Engineering" an der Universität Kiel.

19. Schlagwörter

Marikultur, Fischzucht, Indonesien, DSS, Nachhaltigkeit, Umweltbelastung

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The project aimed at the development of an integrated decision support system for the sustainable management of fish farming activities in Indonesian coastal seas. The system, which relies on a combination of field data, numerical simulations and GIS databases, integrates a set of user-relevant decision criteria in order to support an environmentally compatible development of coastal fish farming. The DSS allows for an optimized site selection for the implementation of fish farm activities as well as a site specific estimation of the ecological carrying capacity of different production and upscaling scenarios. In order to demonstrate the performance of the DSS, the systems has been applied to two coastal areas located in Northern Bali and Sumbawa, respectively, which were designated for development of fish farming by the Indonesian Ministry of Marine Affairs and Fisheries.
The DSS proved suitable in supporting governmental authorities and mariculture industry in the implementation of sustainable marine fish farming activities. Capacity building and hands-on training formed an integral part of the project activities. Training courses were held both in Indonesia and in Germany. Students were actively enrolled in the postgraduate program “Coastal Geosciences and Engineering” of Kiel University at MSc and PhD levels.</td></tr>
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