SPICE Cluster 3.2

Verbundprojekt Indonesien:

Entwicklung einer Systemlösung für ein nachhaltiges Management lebender Ressourcen (Aquakultur)

BMBF-Verbundvorhaben FKZ 03F0393A

Abschlussbericht

01.08.2003 – 31.03.2007

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Abkürzungen

ADCP	Accoustic Doppler Current Profiler
BPPT	Badan Pengkajian dan Penerapan Teknologi (Indonesian Agency for the Assessment and Application of Technology)
CTD	Conductivity-Temperature-Depth Multisonde
CORELAB	Coastal Research Laboratory 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
FTZ	Forschungs- und Technologiezentrum Westküste der Universität Kiel in Büsum
FAO	Food and Agriculture Organization (of the United Nations)
GIS	Geographical Information System
GRIM	Gondol Research Institute for Mariculture
IGBP	Internationale Geosphere-Biosphere Programme
IPB	Institut Pertanian Bogor (Landwirtschaftliche Hochschule Bogor)
ITB	Institut Teknologi Bandung (Technische Hochschule Bandung)
LAPAN	Lembaga Antariksa dan Penerbangan Nasional (The National Institute of Aeronautics and Space)
LIPI	Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences)
LOICZ	Land Ocean Interaction in the Coastal Zone
SPICE	Science for the Protection of Indonesian Coastal Ecosystems
UNRI	Universitas Riau

A. SCHLUSSBERICHT

1. Aufgabenstellung

Vor dem Hintergrund einer zunehmenden Intensivierung der marinen Aquakultur vor allem im Hinblick auf den chinesischen Markt sind Belastungen der Meeresumwelt durch Emissionen von offenen Fischzuchtfarmen in den Küsten- und Inselregionen Indonesiens ein vieldiskutiertes Problem von großer wirtschaftlicher Tragweite. Um derartigen Problemen zu begegnen, ist die Entwicklung wissenschaftlich fundierter Leitlinien für einen nachhaltigen zukünftigen Ausbau der indonesischen Marikultur erforderlich.

Das übergreifende Ziel des Projektes lag darin, auf Grundlage umfassender Felduntersuchungen in Kombination mit computergestützten Modellierungen unter Nutzung von GIS-Technologien ein geschlossenes System konkreter Entscheidungshilfen und Empfehlungen (engl. „Decision Support System – DSS) zu entwickeln, welches im Küstenmanagement zur Raumordnung für den ökologisch nachhaltigen Aufbau und Betrieb von küstennahen Netzkäfigfarmen Verwendung findet. Potenzielle Eignungsgebiete für die Ansiedlung von Fischzuchtanlagen werden anhand gewichteter Umweltkriterien identifiziert und die zulässige Größe und Produktionskapazität der Zuchtbetriebe mithilfe von Modellsimulationen bestimmt.

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

Das Vorhaben wurde im Rahmen der Deutsch-Indonesischen Kooperation in den Meeres- und Geowissenschaften im Verbund mit indonesischen und deutschen Universitäten und Firmenpartnern durchgeführt und vom BMBF mit Bundesmitteln in Höhe von rund 621.000,-- Euro für eine Gesamtlaufzeit von 43 Monaten gefördert. Es ist Teil des bilateralen SPICE-Programms „Science for the Protection of Indonesian Coastal Ecosystems” und hier dem Cluster 3 „Coastal Ecosystem Health“ zugeordnet. Federführend auf deutscher Seite war das Forschungs- und Technologiezentrum Westküste der Universität Kiel (Projektleitung: Prof. Dr. R. Mayerle) sowie auf indonesischer Seite die Universität Bogor/Java, Institut Pertanian Bogor (Dr. Indra Jaya). Als weiterer Partner beteiligte sich die Universität Riau/Sumatra, Fakultas Perikanan dan Ilmu Kelautan, Pekanbaru (Prof. Dr. F. Feliatra) an dem Vorhaben. Deutscher Firmenpartner war die Coastal Research and Management GbR (CRM), Kiel (Dr. L. Piker) sowie auf indonesischer Seite die Fischzuchtfirmen PT Nuansa Ayu Karamba, Farm

& Multi Species Hatchery, Jakarta (General Manager Mr. Martin Hadinito) und Hiang Fishery, Pulau Serai, Tanjung Pinang/Riau (General Manager Mr. Cu Yang).

Ergänzend zu den beiden im Rahmen der Zuwendung bewilligten Doktorandenstellen beteiligten sich zwei über den DAAD geförderte indonesische Doktoranden an den Forschungsarbeiten. Die erheblichen logistischen Anforderungen für die umfangreichen Messkampagnen in Indonesien konnten nur durch Bereitstellung zusätzlicher Personalkapazität aus Eigenleistung erfüllt werden. Die Abwicklung der temporären Einfuhrgenehmigung und der Zollabfertigung gestaltete sich umständlich, dank der Unterstützung der indonesischen Partner ergaben sich hieraus jedoch nur geringe zeitliche Verzögerungen. Ebenso war die Beantragung der Forschungsgenehmigungen mit einem hohen bürokratischen Aufwand verbunden. Die Gültigkeit der von LIPI (Indonesian Institute of Sciences) ausgestellten Forschungsgenehmigung wurde von den lokalen Marinebehörden auf Bintan nicht anerkannt.

3. Planung und Ablauf des Vorhabens

Die detaillierte Planung des Vorhabens wurde auf einem Implementationstreffen mit den indonesischen Partnern in Jakarta im Herbst 2003 festgelegt. Als Untersuchungsgebiete zur Entwicklung des Decision Support Systems wurden eine Inselregion nördlich von Jakarta (Seribu Islands/Pramuka) sowie eine Region des Riau-Archipels (Bintan/Pulau Serai) südlich von Singapore ausgewählt (Abb. 1). Zielobjekte waren bestehende Zuchtbetriebe des marktwichtigen „Grouper“ (Barscharten) und Milchfisch, die in Zukunft erweitert werden sollen. Das softwaregestützte Endprodukt „DSS“ sollte am Beispiel dieser Fallstudien entwickelt werden und über numerische Modellsimulationen eine Einschätzung der umweltverträglichen Ausbaufähigkeit gestatten.

Die F&E-Arbeiten im Vorhaben gliederten sich in die Bereiche Indikation, Datenermittlung, numerische Modellierung und Felduntersuchungen. Die Indikation umfasste die Festlegung von Kriterien und Grenzwerten für die Eignung eines Küstenbereiches als potenzielles Fischzuchtgebiet. Die Datenermittlung diente der Quantifizierung der ausgewählten Kriterien anhand existierender Datensätze und eigener Feldmessungen als auch der Bereitstellung von Basisdaten (e.g. Bathymetrie, Meteorologie) zur Entwicklung der numerischen Modelle. Die Modellierungsarbeiten umfassten die Entwicklung eines hydrodynamischen Strömungsmodells sowie eines gekoppelten Wasserqualitätsmodells zur Simulation der Nährstoffausbreitung in den beiden Untersuchungsgebieten. Zum Betrieb sowie zur Kalibrierung und Validierung der Modelle wurden in saisonalen Feldmesskampagnen umfangreiche Datensätze zu den hydrographischen, nährstoffchemischen und biologischen Verhältnissen in den Untersuchungsgebieten erhoben. Sediment und Depositionsuntersuchungen erfolgten im Rahmen eines Unterauftrags an die Fa. Coastal Research and Management, Kiel, die ebenfalls die Installation der Unterwassermessgeräte (Strömungsmesser, Pegelmessnetz) übernahm.

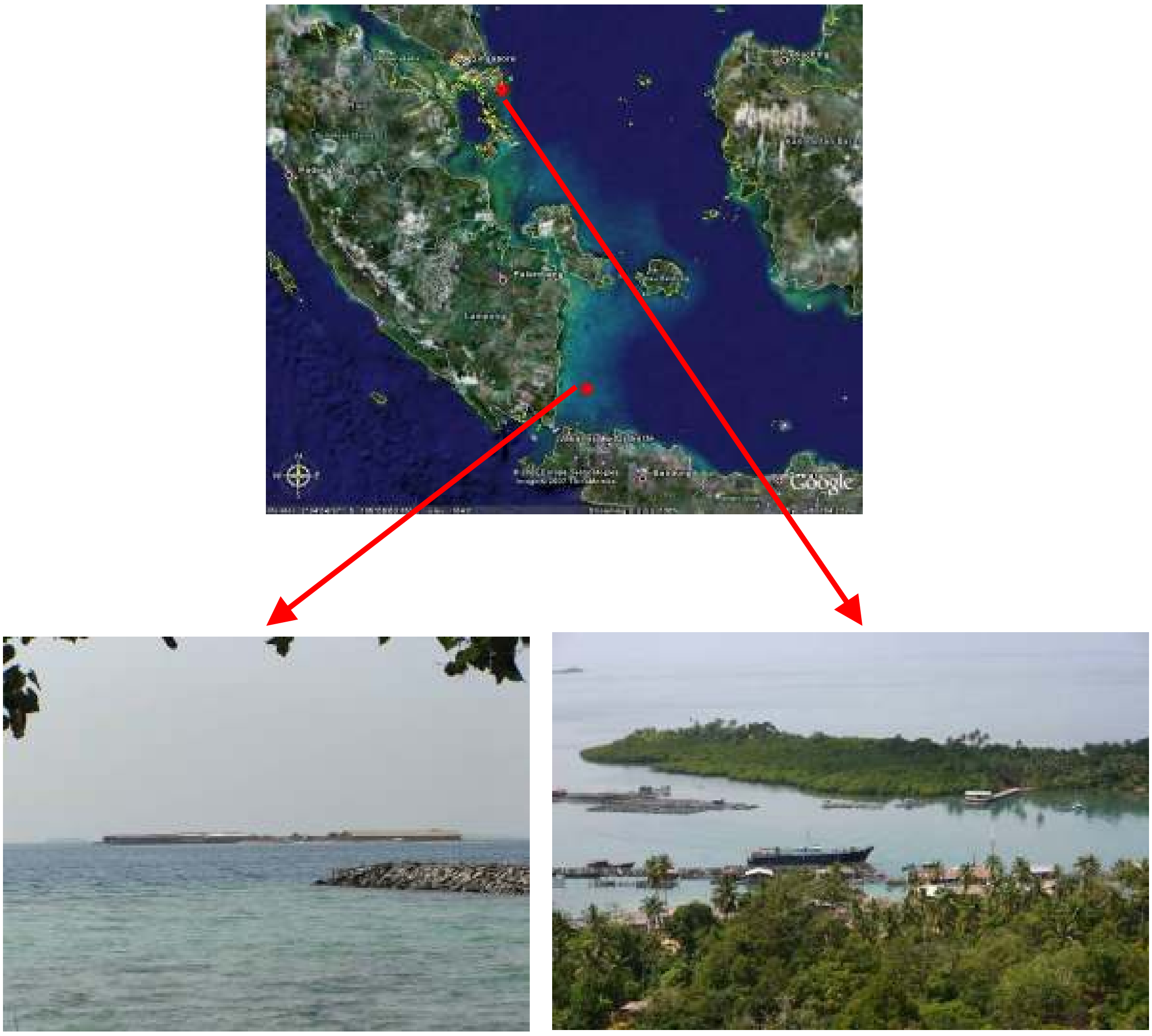

Abb. 1: Untersuchungsgebiete (links: Pulau Pramuka; rechts: Pulau Serai)

Im Zeitraum des Vorhabens wurden zwei Intensiv-Messkampagnen in jedem der Untersuchungsgebiete durchgeführt, die jeweils zur Trocken- und zur Regenzeit stattfanden. Für die Feldmessungen wurden ein mit moderner Messtechnik (ADCP, CTD, GPS, Dataloggersystem) ausgerüstetes Forschungsboot und umfangreiches Gerätematerial als Containerfracht nach Indonesien verbracht. In den Untersuchungsgebieten wurden die Strömungsverhältnisse, die Salz- und Temperaturgradienten, die tidenzyklischen Nährstoffeinträge an den offenen

Rändern der Modellgebiete, die Fischfarmemissionen und deren potenzielle Eutrophierungseffekte im Wasser und am Boden, die räumliche Ausbreitung der Emissionen sowie der Fischfarmbetrieb selbst (Besatz, Produktion, Art und Menge des Futters etc.) untersucht. Weiterhin wurde in beiden Gebieten eine meteorologische Station zur kontinuierlichen Erfassung der Windrichtung und Geschwindigkeit und der Lufttemperaturen sowie ein Messnetz zum Monitoring der Wasserstände jeweils für einen Zeitraum von 6 Monaten aufgebaut.

In Ergänzung zu den Felduntersuchungen wurden mehrere Arbeitstreffen, Vorträge sowie ein Trainings-Workshop in Indonesien abgehalten. Die folgende Tabelle (1) gibt eine Übersicht zu den wichtigsten Aktivitäten.

Tab. 1: Durchgeführte Aktivitäten

Datum	Ort	Durchgeführte Aktivität
01.08.03		Beginn des Projektes
27.09.-06.10.03	Jakarta	Implementationstreffen mit Besichtigung der Untersuchungsgebiete
02.10.-20.10.04	Seribu Inseln	Erste Intensivmesskampagne
10.2004	Bali	Vorstellung des Projektes am Gondol Research Institute for Mariculture
seit 2005	Bandung	Planung eines gemeinsamen Master-Studiengangs „Double-degree Master of Science in Coastale Geosciences and Engineering“ mit ITB
03.04.-24.04.05	Seribu Inseln	Zweite Intensivmesskampagne
04.2005	Seribu Inseln	“Field Training Course on Coastal Environmental Techniques”
13.09.-01.10.05	Bintan	Dritte Intensivmesskampagne
09.2005	Seribu Inseln	Workshop mit Buparti Rahmadan, Wissenschaftlern vom IPB/ITB und politischen Entscheidungsträgern: „Scientific and Economic Development of Seribu Province“
09.2005	Jakarta	APEC Workshop: „Ocean Models for the APEC Region“ (WOM-15)
25.04.-20.05.06	Bintan	Vierte Intensivmesskampagne
05.2006	Jakarta	Präsentation des DSS am Central Research Institute for Aquaculture
14.11.-16.11.06	Denpasar	“SLAS Conference Southeast Asia Coastal Governance and Management Forum: Science meets Policy for Coastal Management and Capacity Building”
11.2006	Bali	Kooperationstreffen am Gondol Research Institute for Mariculture zur Vorbereitung einer Projektanschlussphase
11.2006	Bandung	Übergabe eines Forschungsbootes der Universität Kiel an das Institute of Technology Bandung durch den Forschungsdezernenten der CAU
31.03.07		Abschluss des Projektes

4. Wissenschaftlicher und technischer Stand, an den angeknüpft wurde

Die Entwicklung des GIS-gestützten DSS basiert auf den von Nath et al. (2000) beschriebenen Prinzipien. Die Auswahl der Kriterien zur Eignung eines Küstengebietes für die Fischzucht wurde auf Basis der FAO-Richtlinien (FAO, 1989) durchgeführt. Zur Berechnung hydrodynamischer Kenngrößen (Strömung, Seegang), der Schubspannung sowie der Nährstoffausbreitung wurde das Delft3D-Modellsystem (Delft Hydraulics, the Netherlands) verwendet.

Delft Hydraulics (2005): DELFT3D-FLOW, User Manual, release 3.25, 2005; DELFT3D-WAQ. User Manual, release 4.00, 2003, Delft Hydraulics, the Netherlands.

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

Nath, S.S., Bolte, J.P., Ross, L.G. & Aguilar-Manjarrez, J. (2000): Application of geographical information systems (GIS) for spatial support in aquaculture. Aquacultural Engineering, Vol. 23, S.. 233-278.

4.1 Benutzte Informations- und Dokumentationsdienste

Topographie und Bathymetrie der Modellgebiete wurden aus vorhandenen Kartenmaterial, letzteres auch aus eigenen Messungen, erstellt. Der hydrodynamischen Antrieb an den seewärtigen offenen Rändern der regionalen Modelle erfolgte mit astronomischen Tidendaten des Global Ocean Tide Modells (TPXO 3.0).

Weitere Datenquellen zur Entwicklung des DSS waren Messreihen zu Wasserständen, Sedimentbeschaffenheit und Topographie der indonesischen National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL), Seawatch-Daten des BPPT (Indonesian Agency for the Assessment and Application of Technology), hydrographische Messreihen von LAPAN (Indonesian National Institute of Aeronautics and Space) sowie des ITB (Bandung Institute of Technology) und des National Oceanographic Data Center (NODC, USA). Die folgende Tabelle (Tab.2) gibt eine Übersicht zu den verwendeten Informationsquellen.

Tab. 2: Übersicht zu den verwendeten Informationsquellen

Nr.	Project/Agency	Parameters/Data Type
1.	BAKOSURTANAL (*Badan Koordinasi Survey dan Pemetaan Nasional*) National Coordinating Agency for Surveys and Mapping	- Hourly water level (26 stations, 1995 – 2000) - Bottom sediment type map - Coastline of Indonesia (ArcGIS format)
2.	DISHIDROS (*Dinas Hidro-Oseanografi*) Hydro-Oceanographic Service	Bathymetry data from the following charts: - Sea Chart Nr. 414-KK : Jukung to Peniki Island 1 : 50,000 - Sea Chart Nr. 941A : Singapore Strait to Java Sea 1 : 1,552,500 - Sea Chart Nr. 2056 : Selat Sunda and Approaches 1 : 250,000 - Sea Chart Nr. 3482 : Singapore Strait to Song Sai Gon 1 : 500,000 - Sea Chart Nr. 3946 : Port Klang to Malacca 1 : 200,000 - Sea Chart Nr. 3947 : Malacca to Singapore 1 : 200,000 - Sea Chart Nr. 3949 : Riau Strait 1 : 125,000
3.	BPPT (*Badan Pengkajian dan Penerapan Teknologi*) Agency for the Assessment and Application of Technology	SEAWATCH buoys time series data from the buoy in Seribu Islands (November 1998 – August 1999) and Bintan Islands (March – September 1999) for the following parameters: - Current velocity and direction - Water temperature - Salinity - Wave height and period - Wind speed and direction - Air pressure - Air temperature
4.	LAPAN (*Lembaga Antariksa dan Penerbangan Nasional*) The National Institute of Aeronautics and Space	Field measurements data on July 2005 at Seribu Islands for the following parameters: - Current velocity and direction - Depth - Light penetration - Water temperature - Salinity - PH - DO - BOD - Chlorophyll-a
5.	DKP (*Departemen Kelautan dan Perikanan*) Ministry of Marine Affairs and Fisheries	Indonesian fisheries statistics (including mariculture)

6.	SEKNEG (*Sekretariat Negara*) National Secretary	Mariculture regulations
7.	Hydrography Working Group, Faculty of Civil Engineering and Planning, Bandung Institute of Technology	Field measurement data on December 1999 and February 2000 at Pramuka Island for the following parameters: - Current velocity and direction - Bathymetry - Wave height and period - Salinity - Temperature - Wind speed and direction - Air temperature
8.	National Center for Environmental Prediction (NCEP) – USA	Global six hourly reanalysis data with the resolution of 1.87 degrees (192 x 94 grid) for wind and sea level pressure
9.	National Oceanographic Data Center (NODC) – USA	World Ocean Atlas (WOA) 2001, which provides monthly, seasonal and annual average values in 33 standard depths and one degree resolution for: - Water temperature - Salinity - Dissolved oxygen - Apparent oxygen utilization - Percent oxygen saturation - Phosphate - Nitrate - Silicate - Chlorophyll - Plankton Biomass World Ocean ¼ degree resolution world wide data of Salinity and Temperature
10.	National Geophysical Data Center (NGDC) – USA	ETOPO-5, which provides 2 minutes resolution of Earth's topography data

5. Zusammenarbeit mit anderen Stellen

Außerhalb des eigentlichen deutsch-indonesischen Projektverbundes mit dem Institut Pertanian Bogor (IPB) und der Universität Riau (UNRI) in Pekanbaru erfolge eine Zusammenarbeit mit dem indonesischen Institute of Technology in Bandung (ITB, Prof. Mira, Dr. Poerbandono), das sich an den hydrodynamischen Messungen in den beiden Untersuchungsgebieten beteiligte und bei der Organisation der Trainingsaktivitäten sowie des Transportes behilflich war. Einen engen Austausch gab es mit dem DAAD Jakarta (Frau Dr. Krüger-Rechmann) in Bezug auf die über DAAD-Stipendien finanzierten indonesischen Doktoranden, die mit Spezialfragestellungen in dem Projekt eingebunden waren. Mit dem ITB wurden darüber hinaus Gespräche zur Etablierung eines Double-Degree im Masterstudiengang Coastal Geosciences and Engineering geführt, die nun in eine konkrete Planungsphase mündeten. Ein ständiger Informationswechsel bestand mit dem Bupati der Seribu Inseln, Herrn Rahmadan. Der Fortgang des Projektes wurde auf mehreren Treffen in Jakarta präsentiert. Eine weitere Zusammenarbeit erfolgte mit Herrn Prof. Sugama vom DKP (Departemen Kelautan Dan Perikanan = ministerielle Behörde für marine Angelegenheiten und Fischerei), Jakarta sowie mit Herrn Dr. Hanafi vom Gondol Research Institute for Mariculture auf Bali hinsichtlich der Skizzierung anschließender Forschungsaktivitäten. Die deutsche Botschaft in Jakarta (Herr Dr. Rottmann, Scientific Counselor) unterstützte in administrativen Fragen.

6. Darstellung der erzielten Ergebnisse

Im folgenden Berichtsteil sind die im Forschungsvorhaben erzielten Ergebnisse in Form einer Serie von übergreifenden Manuskripten dargestellt, die die wissenschaftliche Substanz des Vorhabens weitgehend wiedergeben und zur Veröffentlichung eingereicht bzw. vorbereitet wurden.

A Decision Support System for the Sustainable Environmental Management of Marine Fish Farming

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The development of a decision support system (DSS) for the optimum selection of marine fish farming sites and the determination of the allowable farm size with respect to environmental sustainability is presented in this paper. The DSS, which combines GIS technologies and numerical simulation models, has been tailored for applications in a wide range of coastal environments. It basically consists of three steps. In the first step, coastal sea areas are pre-screened for sites suitable for cage fish farming on a regional scale considering key physical and chemical properties, sediment characteristics and coastal utilization. In a second step, the most suitable locations for fish farming at the selected sites are identified on a local scale, taking into account water depths, bed slopes, current velocities, wave exposure and bed shear stresses. Finally, the maximum allowable stock size at the selected sites is determined by comparing the results of numerical model simulations of nutrient enhancement resulting from fish farming operations with acceptable limits for environmental sustainability. Numerical models for simulating flow, waves and water quality are applied to the coastal environments. The functionality of the DSS is demonstrated by considering the western part of the Java Sea in Indonesia. The results confirm the suitability of the system for supporting governmental authorities in the implementation, environmental control, and estimation of the overall carrying capacity of environmentally sustainable marine fish farming.

Keywords: Mariculture, Sustainable Environmental Management, Decision Support System

1. Introduction

During recent decades a number of investigations have well underlined that emissions of dissolved and particulate nutrients from aquaculture operations through feed wastage, fish excretion and faeces production may have a serious impact on the aquatic environment (e.g. Krom and Neori, 1989, Seymour and Bergheim, 1991, Brown et al., 1987, Rosenthal, 1994, Pereira et al., 2004, Porello et al., 2005). In general, dissolved matter released from such operations tends to spread and undergo rapid dilution. However, in areas with poor flushing, deterioration of water quality within the cages and in the surrounding area may occur. Settling particles, on the other hand, are mainly confined to the fish farm area and readily sink. This may, however, lead to deterioration of the benthic communities beneath the cages. The extent of the environmental impact due to fish farming depends primarily on the species involved, the culture method, stocking density, feed type and quantity, environmental conditions and husbandry practices.

Rosenthal (1995, 2001) identifies research needs and precautions that should be taken to ensure the sustainability of aquaculture development and to more adequately manage environmental impacts. Standardized monitoring programmes and simulation models which take into account biological, technical and socio-economic aspects are recommended. The results of several investigations have also shown that the harmful effects of cage fish farming can be significantly reduced by careful site selection, adequate stock density, improved feeds and better farming practices, including integrated polycultures. Procedures for the selection of suitable fish farming sites on the basis of key parameters have been proposed (Pérez et al., 2005, BPPT, 2001, Nath et al., 2000, FAO, 1989, KLH, 1984, DITJEN PERIKANAN, 1982). GIS technologies were introduced to facilitate the handling of the large amount of information involved in the selection (e.g. Riqqi, 2001, Suhey et al., 2005). Rapid advancements in the numerical modelling field have led to the development of simulation models of hydrodynamics and water quality to support the management of fish farm operations. Results of the simulations were used to predict dissolved nutrient loadings from the farm operation and their eutrophication potential in the water column (Gowen et al., 1994, Kishi et al., 1994, Wu, 1995 and Wu et al., 1999) as well as the deposition of particulate matter and associated changes in the zoobenthic community (Gowen and Ezzi, 1992, Lee et al., 2003, Cromey et al., 2002, and Alver et al. 2004). Information on the hydrography and topography of the site and the expected environmental impact in relation to farm specifications has been used to estimate the holding capacity of sites for fish farming (Stigebrandt and Aure, 1995 and Stigebrandt et al., 2004).

In this paper a decision support system (DSS) for site selection, identification of the most suitable locations and the determination of holding capacities for environmentally sustainable marine fish farming is introduced. The DSS combines GIS technologies and numerical simulation models. Model development is done based on data obtained from field measuring campaigns. The development and preliminary results of the application of the system for site selection covering the West Java Sea (Indonesia) are presented. Identification of the most suitable areas for caged fish farming and the determination of critical fish farm sizes are demonstrated by way of an island development scheme northwest of Jakarta.

2. Decision Support System for Sustainable Management of Mariculture

The system consists of three steps, as indicated in Fig.1. Firstly, the coastal regions are pre-screened on a regional scale for sites best suited to fish farming operations. These are identified on the basis of key parameters and conflicting interests of coastal use. Secondly, the most suitable locations for fish farming operations within the selected sites are identified. Finally, the fish farming holding capacity at the selected sites in terms of environmental sustainability is determined on the basis of numerical model simulations of flow and nutrient enhancement levels resulting from fish farming. The DSS combines GIS technologies and implements commercially available numerical models for the simulation of flow, waves and water quality. A more detailed description of the steps involved is given in the following.

Step 1 – Pre-screening of the investigation area for site selection on a regional scale: Suitable sites for fish farming are identified on the basis of weighted key physical and chemical parameters, sediment characteristics and coastal utilization, as listed in Table 1 (Pérez et al., 2005, BPPT, 2001, Nath et al., 2000, FAO, 1989, KLH, 1984, DITJEN PERIKANAN, 1982). Higher weightings are assigned to water depths, current velocities and distances to industrial areas. Studies of floating cage fish farming practice in Indonesia have shown that marine fish farms should be set up in water depths varying from about 5 to 15m, with current velocities ranging from 0.2 to 0.5m/s (BPPT, 2001). Moreover, fish farms should be located at a sufficiently large distance from conflicting coastal activities. The DSS was designed to permit the integration of additional parameters in the selection procedure. Data handling and data processing are performed in raster format using a GIS application (ESRI ArcGIS). The pre-screening involves: a) gathering of the information listed in Table 1 and subsequent storage in the GIS database; b) conversion of the data to raster format; c) assignment of suitability scores to each parameter; d) determination of relative importance weightings by means of the *Analytical Hierarchy Process* proposed by Saaty (1980); e) spatial classification of suitability for fish farming on the regional scale by superposition of the various contributions.

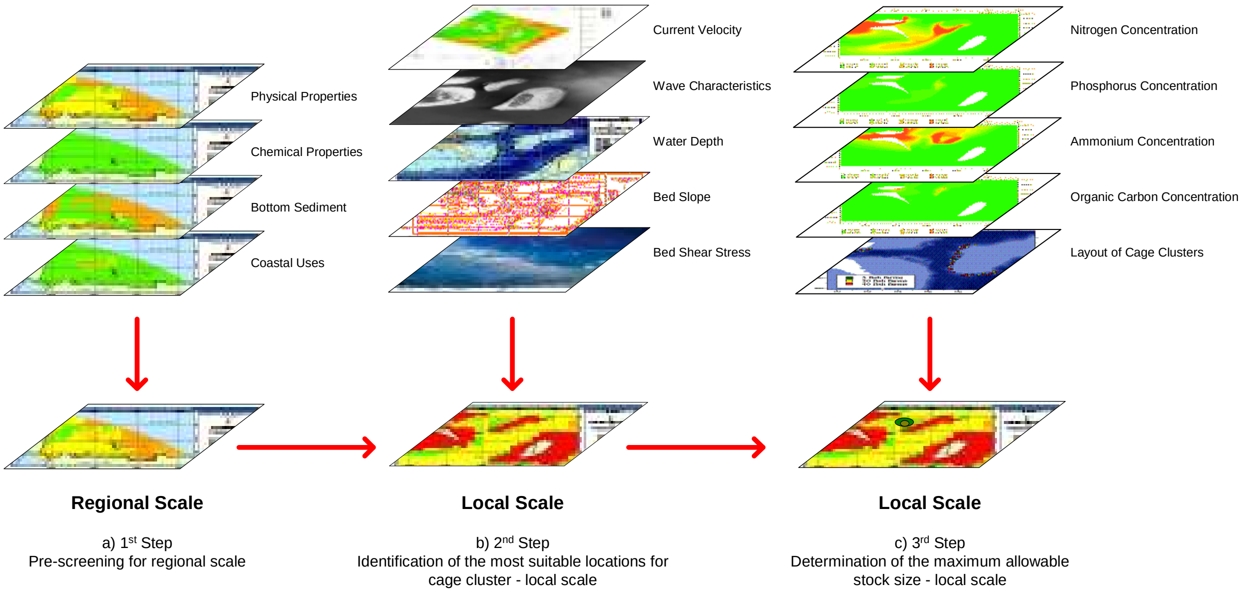


Fig 1: DSS Modules for the Sustainable Environmental Management of Marine Fish Farms

Table 1: Parameters considered for site selection of floating cage fish farms in tropical coastal areas

		Score				Weighting
		Unacceptable =0	Poor = 1	Fair = 2	Good = 3	
Physical	Maximum Depth at Spring Tide (m)	< 3	3-5 or > 20	15-20	5-15	**0.157**
	Maximum Current Velocity (m/s)	< 0.05 or > 1	0.05-0.2	0.5-1	0.2-0.5	**0.157**
	Maximum Wave Height (m)	>1.5	1-1.5	0.6-1	≤ 0.6	**0.077**
Chemical	Water Temperature (°C)	< 15 or > 35	15-20 or 33-35	20-27 or 31-33	27-31	**0.022**
	Salinity (psu)	< 10	10-15	15-25 or > 35	25-35	**0.022**
	Dissolved Oxygen (ppm)	< 4	-	4-5	≥ 5	**0.072**
	Ammonium (ppm)	0.5	-	-	≤ 0.5	**0.072**
	Water pH	< 3 or > 14	-	3-7.8 or 8.6-13	7.8-8.6	**0.072**
	Nitrate (mg/l)	> 200	-	-	≤ 200	**0.072**
	Phosphate (mg/l)	> 70	-	-	≤ 70	**0.072**
Sed.	Bottom sediment type	-	Mud	Coral	Sand	**0.010**
Coastal Utilization	Distance to harbour (km)	< 0.2	-	0.2-0.5	≥ 0.5	**0.013**
	Distance to navigation line (km)	< 0.2	-	0.2-0.5	≥ 0.5	**0.013**
	Distance to industrial area (km)	< 1	1-2	2-5	>5	**0.157**
	Distance to tourism area (km)	> 0.5	-	0.5 – 1.5	≥ 1.5	**0.013**

Step 2 – Detailed identification of the most suitable locations for cage clusters: Once suitable sites for fish farming activities have been selected on a regional scale, the most suitable locations for establishing fish farms within these sites are identified. An extended procedure involving a combination of flow and wave model simulations is adopted. The areas suitable for setting-up cage clusters are selected on the basis of water depths, bed slopes, current velocities, exposure to waves and bed shear stresses. Water depths and bed slopes are derived from bathymetrical measurements or nautical charts. The remaining information is obtained from numerical model simulations using existing modelling systems. In order to reduce the risk of sediment deterioration beneath the cages the fish farms should be located in regions where the critical bed shear stress is exceeded regularly as well as along the borders of the main channels in regions with higher bed slopes. An overlay of the thematic maps defined by each of the above-mentioned criteria leads to a detailed identification of the most suitable areas for fish farming within the site in question.

Step 3 – Determination of the maximum allowable stock size at the selected sites: The critical stock size in terms of environmental sustainability thresholds is determined from the levels of nutrient enhancement resulting from fish farming. For this purpose coupled models of flow and water quality have been developed for predicting the dispersion patterns of total dissolved inorganic nitrogen, phosphorus, ammonium and organic carbon. Dissolved nutrient loads released from the fish farms are estimated on the basis of feed quantity, growth curves and metabolic ratios for the farmed species in question (Van der Wulp, 2006) and modelled as point sources. Several alternatives in terms of fish farm sizes and lay-outs are tested for the full range of conditions typical of the site in question, which was selected in step 2. The predicted nutrient levels due to the various fish farm settings are compared with environmental threshold values related to natural background concentrations.

3. Development of the DSS for application in Indonesian coastal waters

With the aim of supporting the management of marine fish farming in Indonesian coastal waters, the DSS was implemented to guarantee environmental sustainability. Pre-screening for site selection on a regional scale (1st step of the DSS) was carried out in the West Java Sea and the Riau Archipelago in Indonesia (Fig. 2). A detailed identification of the most suitable areas for setting up cage fish farms (2nd step) as well as a determination of the holding capacity (3rd step) were undertaken for two coastal sites within these regions: a) a relatively small fish farm situated in the Java Sea amongst the group of Pramuka, Karya and Panggang islands (Seribu islands), about 60 km northwest of Jakarta and b) a much larger fish farm in the Riau Archipelago located near Serai Island in Bintan, southeast of Singapore. Fig. 3 shows views of the fish cages typically suspended from bamboo rafts. The cages are about 3m long, 3m wide, and 4m deep.

The data required for developing the DSS were derived from nautical charts, field measurements, the World Ocean Atlas 2001 (Conkright et al., 2002), and the results of numerical model simulations. Fig. 4 shows the selected coastal areas indicating the field measurement locations. Measurements of wind, water levels, current velocities and nutrient concentrations were made at several locations covering typical conditions during the dry and wet seasons. Water levels were measured using pressure gauges, whereas current velocities were measured using acoustic profilers (ADCP) deployed from moving vessels. Nutrient concentrations were obtained by analysing discrete water samples preserved with mercury chloride according to the method of Grasshoff et al. (1983). Grab samples at several locations underneath and around the cages were analysed for the sediment type.

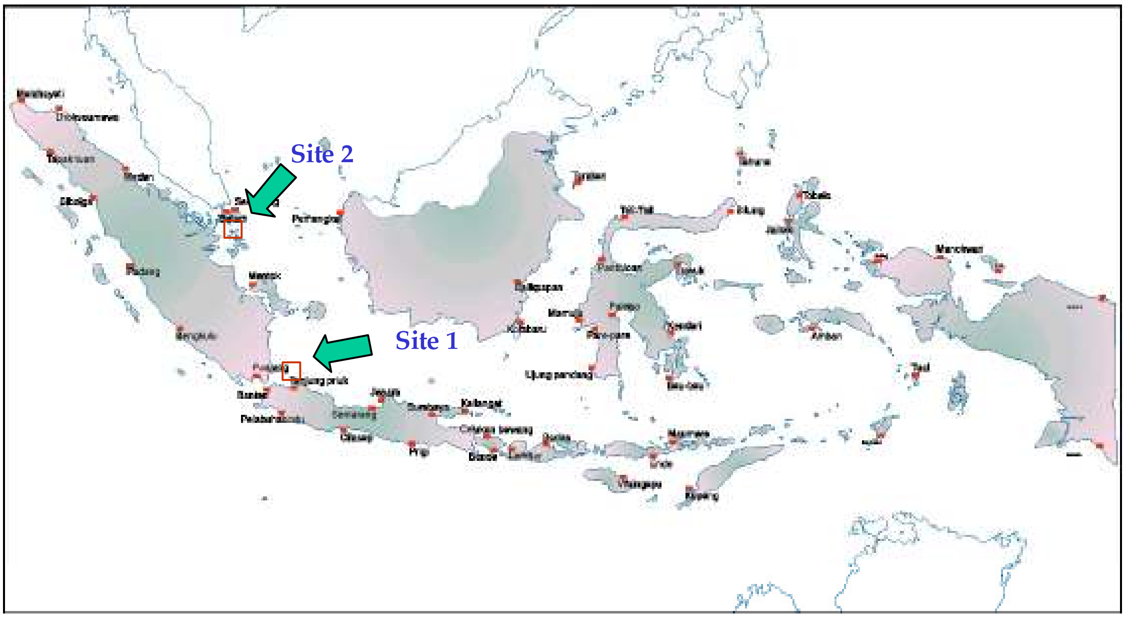


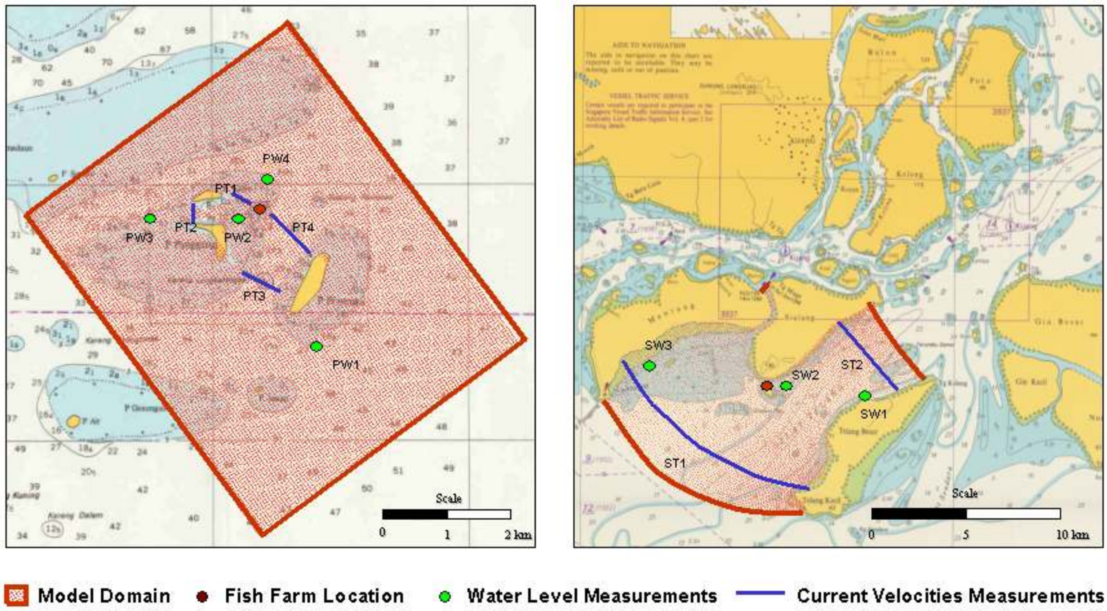
Fig. 2: Location of the study sites in Indonesian coastal waters

Process-based models for simulating flow, waves and water quality were developed and subsequently calibrated and validated using field data. Two-dimensional depth-integrated (2DH) flow and water quality models based on the DELFT3D Modelling System developed by Delft Hydraulics in the Netherlands (Roelwink and Van Banning, 1994) as well as the phase-averaged spectral wave model SWAN (Booij et al., 1999, Ris et al., 1999) were used for this purpose. The flow model solves the non-steady depth-integrated momentum and continuity equations for depth-integrated velocities and water levels. The water quality model solves the advection-diffusion equation for nutrient concentrations taking into account the most dominant transformation processes.

Curvilinear grids adjusted to the bathymetry and coastlines, with resolutions varying from 25 to 100m, were developed for the selected sites. Fig. 4 shows the model domains and the local bathymetry. The sizes of the model domains covering the small group of islands northwest of Jakarta and the coastal waters of Serai Island in Bintan are about 20 and 100km^2, respectively. These coastal area models were nested within larger models covering the West Java Sea and the Riau Archipelago, respectively.

a. Pramuka Islands Fish Farm   b. Serai Island Fish Farm

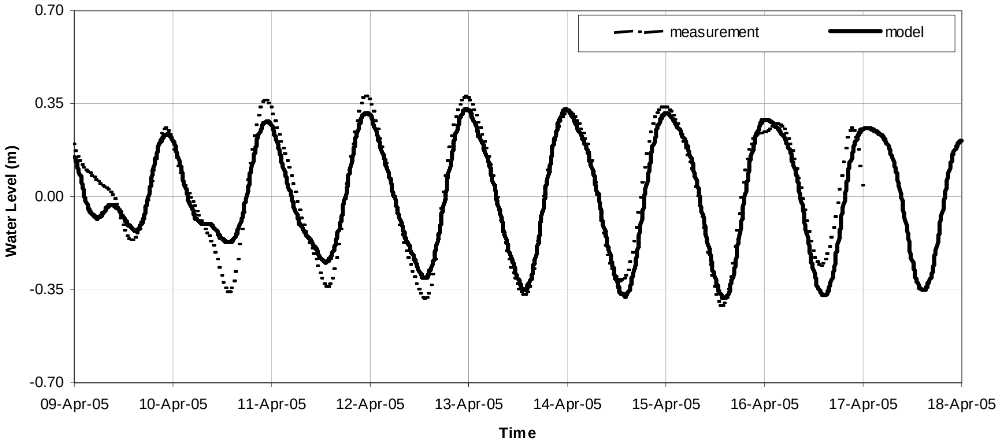
Fig. 3: Fish farms studied for developing the DSS



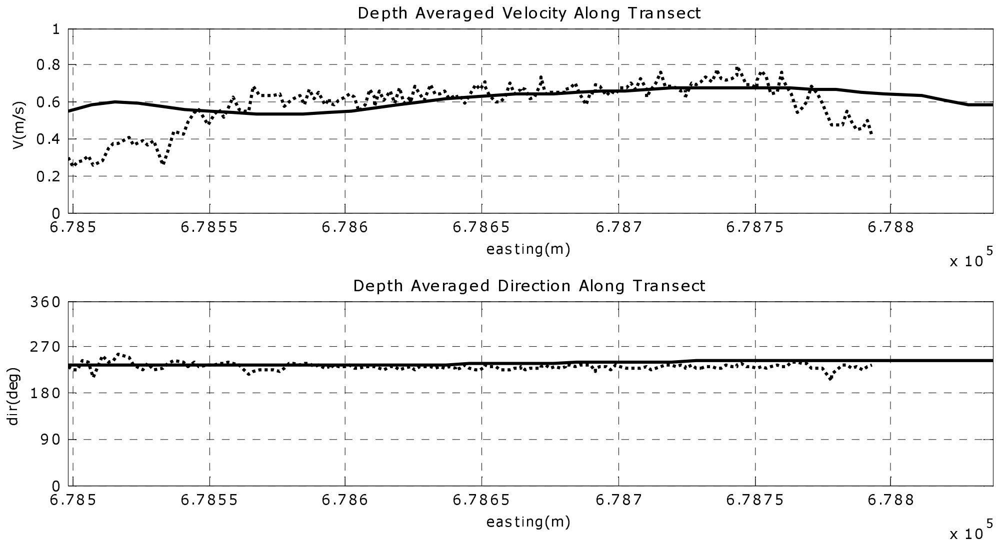
a) Group of islands northwest of Jakarta b) Serai Island southeast of Singapore

Fig. 4: Coastal sites, location of measurements and model domains

Comparisons of the flow model results with field data of a) water levels measured at a gauge station near the fish farm and b) current velocities over a cross-section in the study area northwest of Jakarta are presented in Fig. 5. The high predictive capability of the model with regard to flushing rates in the near vicinity of the fish farms is confirmed by good agreement between the simulated results and field measurements. The water quality models for the coastal sites were calibrated and validated using field data of dissolved inorganic nutrient concentrations. Fig. 6 shows comparisons of modelled and measured near-surface ammonium concentrations at a location in the vicinity of the fish farm. The nitrification of ammonium was taken to be the dominant transformation process in the model simulations. Good agreement was obtained particularly with regard to the level of nutrient enhancement resulting from fish farming activities.



a) Water levels at gauge station PW2



b) Magnitude and direction of current velocity over cross-section PT4

Fig. 5: Measured versus computed water levels and current velocities near the group of islands northwest of Jakarta

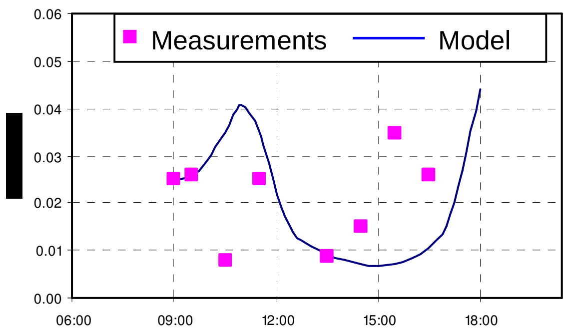


Fig. 6: Measured versus computed ammonium concentrations near the fish farm at Pramuka

4. Demonstration of the DSS

Fig. 7 illustrates the functionality of the DSS for site selection on a regional scale. The operations involved in the pre-screening process for site selection (1st step of the DSS) are shown for the West Java Sea. The resulting suitability maps for fish farming enables the user to proceed with a more detailed analysis on a local scale in order to identify the sites most suitable for fish farming on the basis of extended criteria imposed at higher spatial resolution. Fig. 8 shows an amplified view of the pre-screening results for the coastal area surrounding the Seribu Islands northwest of Jakarta, which was taken into consideration by the local authorities as a potential coastal environment for fish farm development.

Within this area, the small group of Pramuka, Karya and Panggang islands was selected for a detailed identification of optimum fish farming locations (2nd step of the DSS). Flow and wave model simulations covering the full range of conditions for the site in question were carried out in order to complement data requirements. The simulations covered neap and spring tides as well as periods with intensive winds. Maps indicating the most suitable locations with regard to water depths, current velocities, bed shear stresses, bed slopes and wave exposure are presented in Figs. 9a to 9e, respectively. The results of superposing the thematic maps for the purpose of identifying the most suitable fish farming locations within the site in question are shown in Fig. 9f. Strips around the islands were identified as optimum sites for placing fish farm cages. The resulting percentages of the area according to its degree of suitability are listed in Table 2. About 0.4 km^2, representing approximately 5% of the total area, was found to be best suited for fish farming on the basis of the specified criteria.

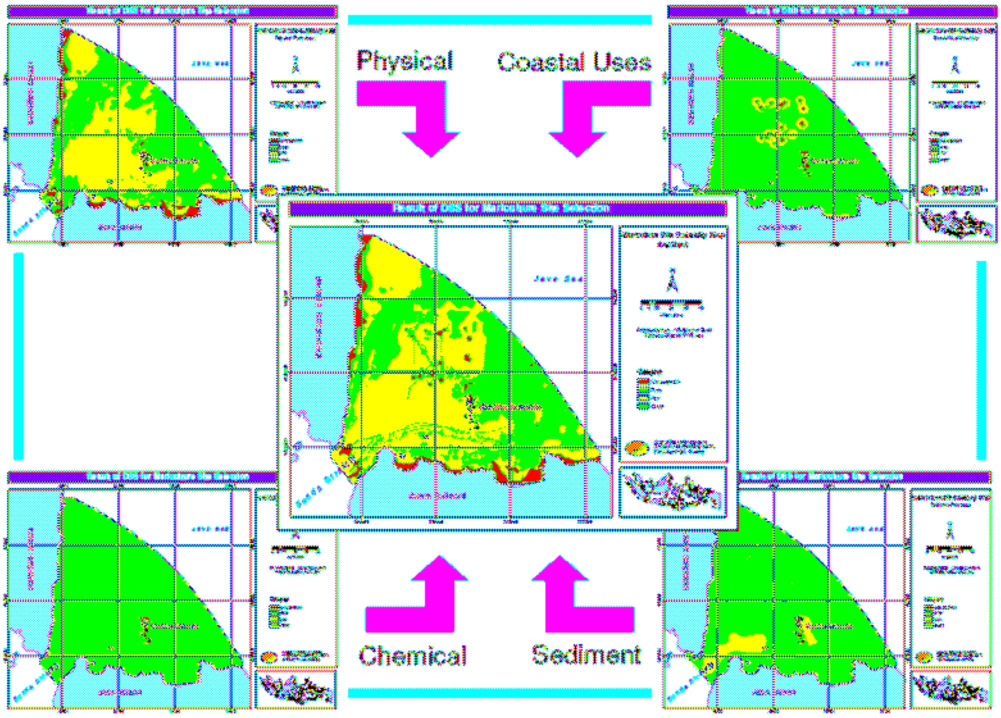


Fig. 7: Pre-screening for site selection on a regional scale (West Java Sea in Indonesia)

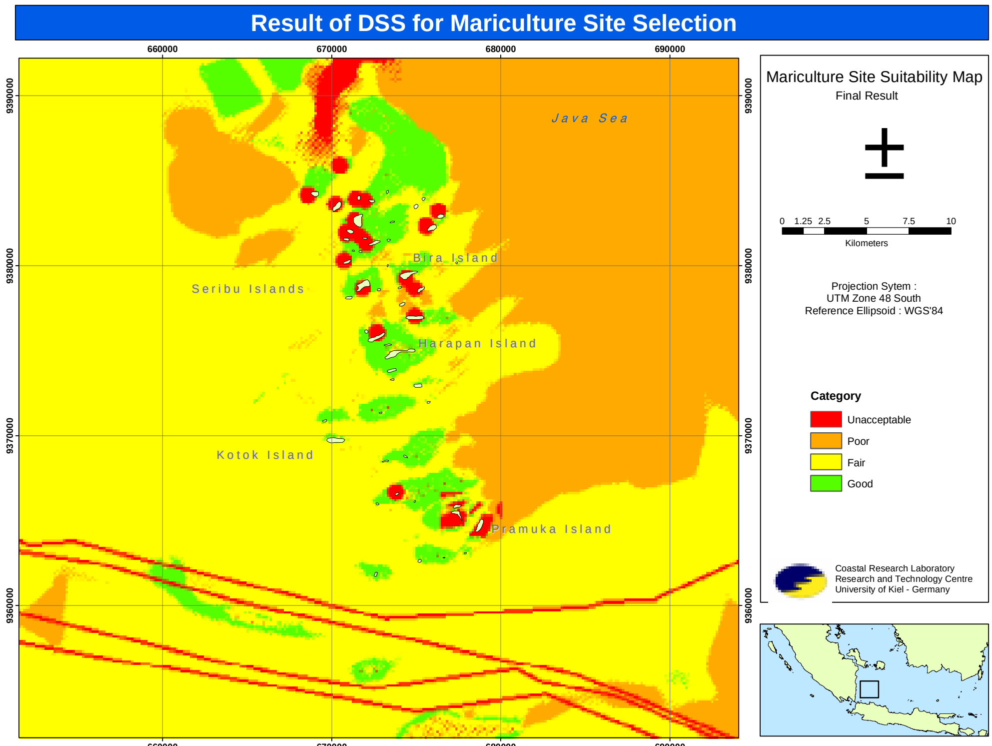


Fig. 8: Pre-screening for site selection on a regional scale (Seribu Islands northwest of Jakarta)

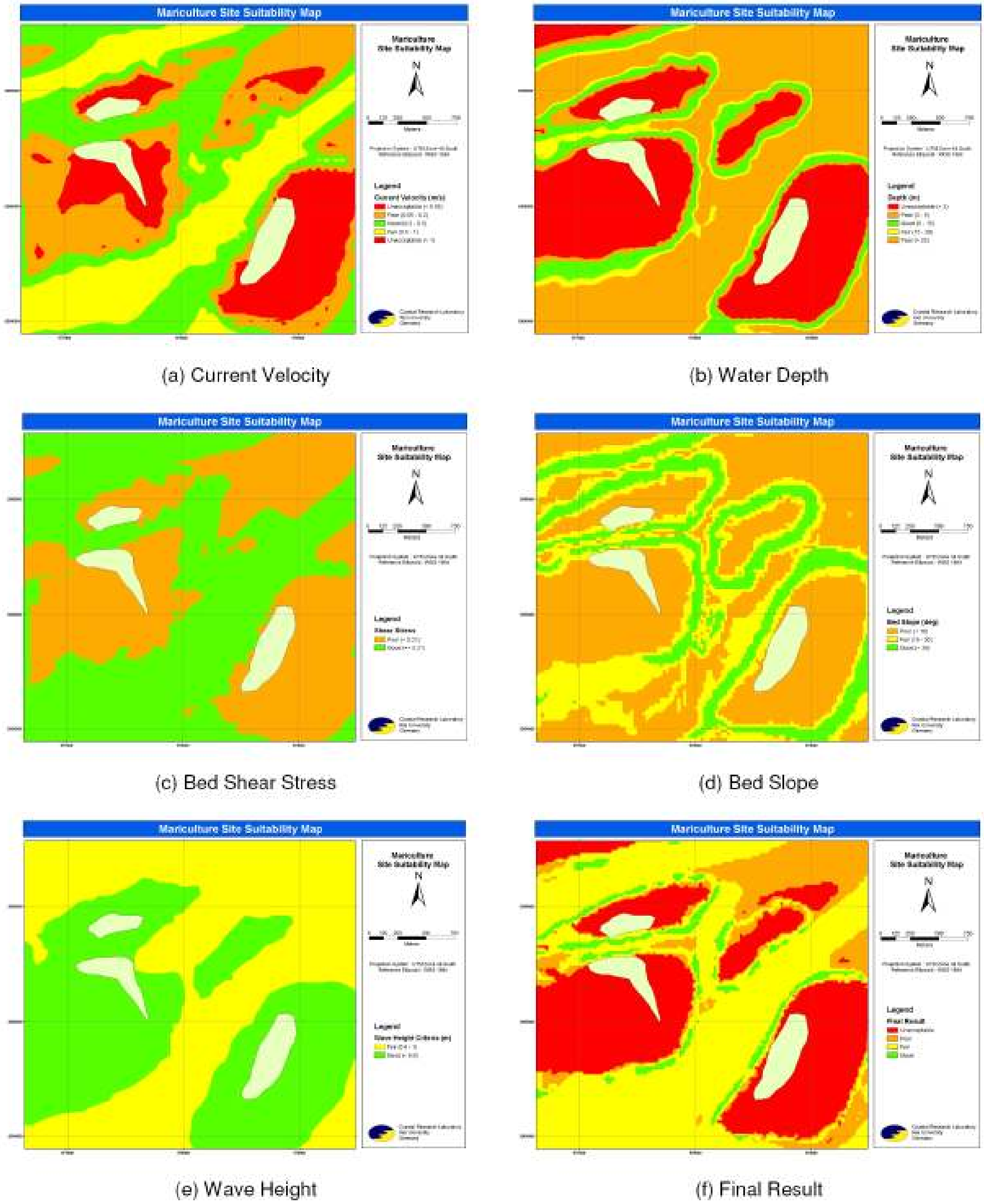


Fig. 9: Detailed identification of optimum areas for fish farming on a local scale for the group of islands northwest of Jakarta

Table 2: Results of the identification of the optimum fish farming locations

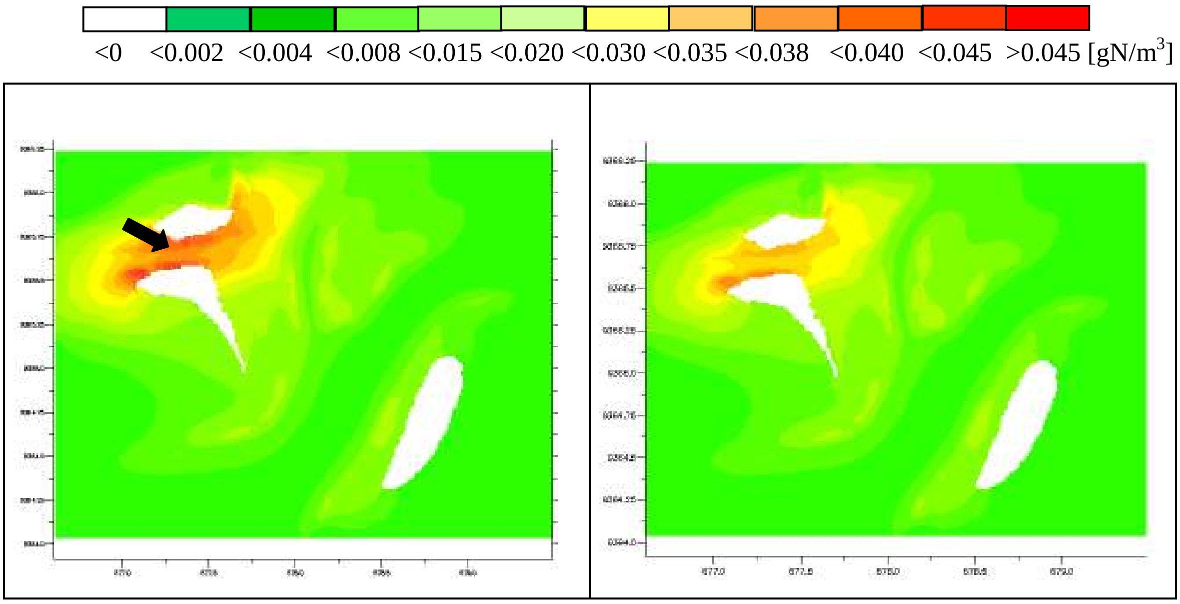
Classification	**Area (km^2)**	**Percentage**
Good	0.4	5
Fair	3.4	44
Poor	1.0	13
Unacceptable	2.9	38

Environmental sustainability was verified by comparing the predicted nutrient levels resulting from various fish farm size settings with acceptable limits of nutrient emissions for environmental sustainability in the sea. Due to a lack of standardized procedures for determining threshold values for environmental sustainability, preliminary verifications were carried out under consideration of the acceptable limits for dissolved inorganic nutrient concentrations in a sea area as defined by the eutrophication assessment procedure of the Oslo-Paris Commission (OSPAR 2005).

According to this procedure, the area specific percentage deviation of nutrient levels should not exceed 50% of natural background concentration values. The latter were estimated from measurements made adjacent to the site in question at locations unaffected by direct anthropogenic activities, disregarding potential transboundary transport from remote areas. Background values for ammonium in the study area were found to be of the order of $0.03 gN/m^3$, resulting in a critical threshold concentration of about $0.045 gN/m^3$ for problem areas.

The estimation of the maximum allowable stock size for the site in question in terms of the environmental sustainability thresholds was determined on the basis of results from water quality model simulations. Virtual fish farms were placed at the locations identified as best suited for fish farming. Predictions of nitrogen, phosphorus, ammonium and organic carbon emissions were computed over the full range of conditions for different fish farm size settings. The dissolved nutrient loads released into the environment were estimated from literature data on the basis of metabolic rates of farmed fish species, taking into account the stock size, growth rates, feed type and quantity (van der Wulp, 2006).

Simulations were carried by placing initially a total of 250 cage clusters containing 16 individual fish cages each, distributed all along the strip of previously identified best suited locations for fish farming (see Fig. 9f). The stock size per cage was set to 500 fish (tiger grouper) with an average weight of 800 gr. Fig. 10 shows the predicted tidally-averaged levels of ammonium for a spring tide with a tidal range of about 0.5m.



a) 250 cage clusters b) 230 cage clusters

Fig. 10: Predicted NH_4 concentrations for the proposed arrangement of the cage clusters.

The simulations reveal that the critical level for the conditions in question is exceeded in the area between the two islands (see arrow in Fig. 10a). By reducing the stock size in the critical area (decrease of the number of cage clusters by 20), the ammonium concentrations resulted within the acceptable limits throughout the entire period (Fig. 10b).

The maximum allowable stock size in terms of the adopted sustainability criteria resulted about 300 tons for the entire area, corresponding to an annual production of approximately 1450 tons. Further optimisations to the lay-out and locations of the fish farms in conjunction with numerical model simulations may lead to increases in the tolerable total capacity. Attention should be given to the criteria of environmental sustainability thresholds which have to be adjusted to the specific conditions in tropical areas. The results confirm the benefits offered by the system for supporting decision-makers in the marine fish farming sector.

5. Future development of the DSS

Future development of the DSS should include additional criteria to take account of initial levels of pollutants in the area derived from external sources (land-based), such as contaminants and endo-bacteria. The latter is of particular relevance in developing regions, in which the sanitary infrastructure is usually poor. Especially in rural areas, it is common practice to discharge waste water without any further treatment directly into the coastal environment. As the successful implementation of fish farming also implies economically sustainable product marketing with exporting opportunities to prospective foreign markets such as Europe, rigorous hygiene standards must be specified and maintained.

The DSS should also be extended to account for potential effects on the benthic regime. Up to now, water quality in terms of hypernutrification has only been considered as a preventive measure for associated eutrophication effects, such as the formation of exceptional algal blooms and oxygen deficiency. A link between particulate organic emissions and sediment deterioration beneath the cages is thus required. Of particular relevance for estimating the holding capacity is the specification of a standardized procedure for the determination of environmental sustainability thresholds especially suited to tropical areas. Currently adopted water quality indices, such as the eutrophication index (TRIX), a composite indicator originally developed for application in the Mediterranean Sea (Vollenweider et al., 1998) which combines nutrient as well as oxygen and chlorophyll criteria, should also be tested to assess their applicability in tropical regions.

6. Acknowledgements

The present study was carried out as part of the SPICE project “Science for the Protection of Indonesian Coastal Environments” funded by the German Ministry of Education and Research (grant number 03F0393A) and the Indonesian Ministry of Fisheries from 2004 to 2007. Responsibility of the content is with the authors. Cooperation with the IPB (Bogor Agricultural University) in Bogor/Indonesia and UNRI (Riau University) in Pekanbaru/Indonesia is very much appreciated. The German Academic Exchange Service (DAAD) is also gratefully acknowledged for providing the funds to finance the doctorate studies of Mr. Wiwin Windupranata and Mr. Taswin Munier.

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Mass balance modelling for determination of nutrient emissions from floating cage fish farms in Indonesia

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Abstract

Since the assessment of floating cage fish farm emissions with field measurements is a complex task because of the open boundary conditions, mass balance modelling could be a good alternative for estimating the loads of emitted nutrients, using relatively little input data that is easily available.

This paper introduces a mass balance model, computing fish growth and cohort sizes over a given period and sets up a mass balance for nitrogen (N), phosphorous (P) and carbon (C) based on the given feed and metabolic ratios.

The model was applied on a fish farm area at Serai Island in Indonesia's Riau Archipelago, where trash fish was the main feed source.

Computed feed conversion ratios approached 6.0 but fluctuated throughout the modelled year. On average, 85 % N, 86 % P and 85 % C of the given feed was found to be lost into the environment. Feed wastage was a significant sink, taking account for 44 % N, 49 % P and 21 % of the total given feed.

Dissolved emitted N, P and C was respectively 34, 9 and 47 percent of the total amount of given feed. Particulate losses were: 49 % N, 75 % P and 37 % C.

These results coincide with several previous studies based on measurements for similar farms in other tropical areas where trash fish was fed.

Quantitatively, emissions fall in the order of magnitude of water quality measurements, done at one of the cage clusters, however further study to verify taken assumptions is necessary.

Model results are a gross output. Further study is necessary to incorporate nutrient strippers such as netfouling and wild feeding. Several processes like microbial decomposition and hydrodynamic displacement are recommended to be analysed using hydrodynamic water quality models, to assess the holding capacity of the area.

Finally, an estimate of the village human waste excretion was done, indicating that it contributes between 1 – 3 % to the anthropogenic nutrient discharge in the area. This is not significant but it might have a strong local effect on the intertidal area where the village is situated.

1. Introduction

Direct assessment of floating cage fish farm emissions with field measurements are labour intensive and time consuming. Because of open boundary conditions of marine cage fish farms, a complex measurement strategy is needed to capture all emitted forms. In contrast, mass balance models are easier to apply and, once calibrated, can provide comparable results. Most studies dealing with aquaculture emissions are based on Salmonid farms operated with formulated feeds (Gowen et al., 1989, Hall et al., 1990, Hall et al., 1992, Hevia, 1996, Holby and Hall, 1991). However, a major part of aquaculture is practiced with non-Salmonid species, fed with trash fish (Wu, 1995, Wu et al., 1994, Wu et al., 1999). Various studies of estimating emissions through mass balance models have been done (Stigebrandt et al., 2004, Islam, 2005, Buryniuk et al., 2006).

In the present study, the development of a model for mass balance calculations of nutrient emissions from marine cage fish farms in coastal areas is presented. The model requires few input parameters concerning fish farm operation and fish metabolism. It calculates fish growth and mortality and the resulting emissions of wasted feed, respiration and faecal excretion for one production year concerning total dissolved and particulate forms of nitrogen (N), phosphorus (P) and carbon (C). After calibration based on similar studies, validation was done for a fish farming area in the Riau Archipelago, Indonesia.

The study site

The study site is located south of Bintan Island between the island of Siulung and the smaller island of Serai (figure 1). Mariculture activity consists of eight floating cage clusters with a total of 500 cages. The nets measure 4x4x3 metres and are fixed in a wooden frame, kept afloat by numerous 200 L drums. The clusters are placed at the borders of a tidal channel, where high current velocities up to 1 m/s occur.

On the south shore of Siulung Island, a small village is located on a tidal flat area.

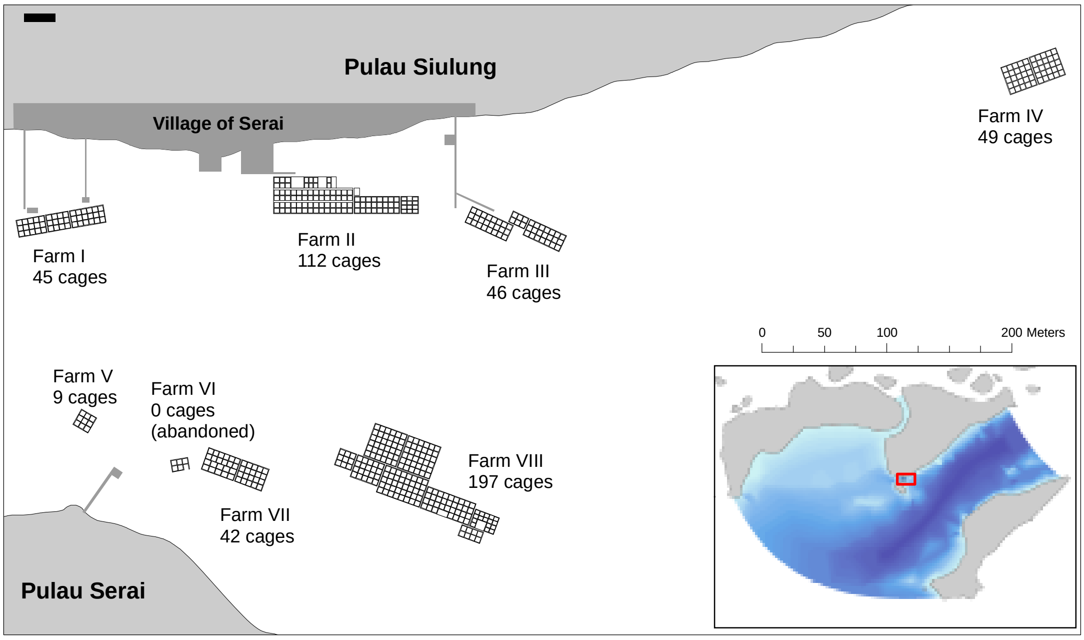

Figure 1: Pulau (Island) Siulung with a focus on the fish farm area and its cage clusters.

Around ten species of Groupers (*Serranidae*), Jacks (*Carangidae*), Wrasse (*Labridae*), Snappers (*Lutjanidae*) and Butterfishes (*Stromateidae*) are cultured for grow-out, obtained from both hatcheries and wild capture. The total annual production within the area is around 114.5 metric tons. Chopped trash fish is given manually throughout the day. Up to 14 % of the diet given, consisted of formulated feed which is mainly used for fingerlings and as addition for the on growing fish in periods when trash fish is scarce.

Considered processes

To model emissions from cage fish farms, several processes were considered as shown in figure x.x. Given feed can be either consumed by fish or discharged into the environment as wasted feed where it settles or is dispersed along with the currents (Gowen et al., 1989).
Feed that is consumed, serves metabolic processes for energy yield (catabolism) and growth (anabolism). Metabolic waste and ingested, but undigested material is discarded as faecal matter (Goddard, 1996).

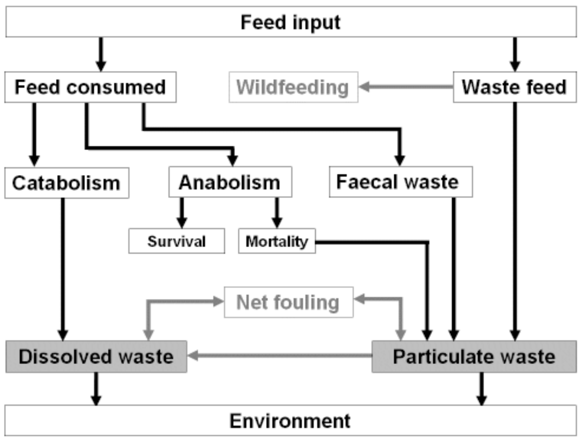

Figure 2: Considered processes around cage fish farms

In terms of emission, catabolic processes result in dissolved compounds such as ammonium and urea, dissolved organic phosphorus and phosphate, organic carbon and carbon dioxide; Faecal matter consists of particulate organic N, P and C (Leung et al., 1999, Wu, 1995)

The model considers emissions until the "fish boundary". Beyond this boundary, emissions are subject to several biological processes such as wild feeding on particulate matter (Felsing et al., 2005), microbial decomposition of organic matter, uptake of readily available nutrients by fouling and non-fouling primary producers (Santoso and Nursetiarso, 1999) and denitrification.

2. Methodology

Production details acquired from the fish farm management were only available for cage clusters II and VIII (figure 1) (Yung, Pers. Comm.). This data contained total feed amounts and numbers of sold fish, target weights, production times and estimated survival rates per species for both clusters for the production year 2004.

With the acquired data, fish growth, stock sizes and mortality were computed for each individual species to determine the increase of biomass throughout the model period using Matlab.

Fish composition and metabolic ratios for N, P and C were applied to compute the anabolized, consumed, catabolized and faecal quantities. The difference between consumed and total feed accounted for the amount of wasted feed. Mortality was calculated separately since its biomass is a share of the anabolized biomass.

The total area emissions were estimated in several steps. First, the model was applied to the cage clusters II and VIII of which the data originates to obtain the feed conversion ratios (FCR's) in the area throughout the modelling period. Since N, P and C are modelled independently from each other, it was decided to consider the so called "Specific FCR's" for N, P and C representing the amount of N, P and C fed per amounts of N, P and C retained in the fish, rather than the FCR of wet weight.

The individual farms were modelled with a production estimate. This estimate was done for each individual farm by surveying each individual cage, noting down species and a percentage estimate of occurrence of species within individual cages. This was then related to the known production of the cage clusters II and VIII. The feeding amounts per individual cluster were determined by multiplying the amount of biomass yield with the 'Specific FCR's' of the first model run.

Model resolution

The modelled period covered one year with monthly time steps, according to the resolution of the acquired feeding data. Fish cohorts were modelled in the calendar year according to the strategy and recruitment as indicated by the fish farm management. It was assumed that every calendar year has a similar production and strategy.

Growth

The fish growth was determined using the weight based Von Bertalanffy method (Pauly, 1986, Sparre and Venema, 1998). The production time (t_{market}), recruitment age (t_0) and target weight (W_{market}) of each species together with the asymptotic weight (W_∞) obtained from literature (Froese and Pauly, 2006) produced the curvature coefficient K using equation 1.

$$K = -ln\left(1 - \left(\frac{W_{market}}{W_\infty}\right)^{1/3}\right) \cdot \frac{1}{t_{market} - t_0} \qquad [1]$$

With the curvature coefficient and the available parameters, the Von Bertalanffy equation (2) was applied, computing the individual weight of the fish (W_t).

$$W_t = W_\infty \cdot \left(1 - e^{-K \cdot (t - t_0)}\right)^3 \qquad [2]$$

The Von Bertalanffy equation was derived in order to find the growth rate.

$$\frac{dW}{dt} = W_\infty \cdot 3 \cdot K \cdot \left(1 - e^{-K \cdot (t - t_0)}\right)^2 \cdot e^{-K \cdot (t - t_0)} \qquad [3]$$

Mortality

To estimate the mortality rates a stochastic model was applied adapted from Sparre and Venema, (1998). Mortality is considered to occur gradually, with mortality being generally higher in the more vulnerable juvenile life stage (Yung, Pers. Comm.).
Mathematically, the mortality coefficient (Z) was formulated as a function of survival rate (S), the production time (t_{market}) and the introduced juvenile success factor (J), responsible for shifting the mortality towards or away from the early life stages.

$$Z = -ln(S) \cdot \frac{1}{t_{market}^{J}} \qquad [4]$$

The number of individuals of a batch of fish at any given time (N_t) could then be expressed as shown in equation 5 where N_0 represents the initial number of individuals.

$$N_t = N_0 \cdot e^{-Z \cdot t^J} \qquad [5]$$

The mortality rate is derived from equation 5.

$$\frac{dN}{dt} = N_0 \cdot J \cdot Z \cdot e^{-Z \cdot t^J} \cdot t^{J-1} \qquad [6]$$

Biomass yield

The amount of biomass is made out of the number of individuals with a certain weight. The rate of biomass increase per unit of time was determined by using equation 7.

$$\frac{dB}{dt} = \frac{dW}{dt} \cdot N_t \qquad [7]$$

Metabolism

The amounts of N, P and C retained in the fish was determined by multiplying the biomass with the average proportion of N (4.42 %), P (0.68 %) and C (19.30 %) determined for Atlantic salmon, *Salmo salar* (Hall et al., 1990, Hall et al., 1992, Holby and Hall, 1991, Holmer et al., 2002).

The retained N, P and C can directly be related to the amount of emission using metabolic ratios (table 1) based on Atlantic Salmon (*Salmo salar*) according to Ramseyer and Garling

(1997) and Gowen et al. (1989) and Areolate Grouper (*Epinephelus areolatus*) as described by Leung (1999).

Table 1: Metabolic ratios for N, P and C as a percentage of the consumed N, P and C.

	Anabolism	*Catabolism*	*Faecal Excretion*
Nitrogen	30	61	9
Phosphorus	32	17	51
Carbon	20	60	20

Consumed and wasted feed

With the given pathways as a percentage of the consumed feed, the respired and faecal amounts of N, P and C can be derived:

$$F_{Consumed} = F_{Retained} + F_{Respiration} + F_{Faecal} \qquad [8]$$

The amounts of given N, P and C were determined considering the compositions of trash fish and formulated feed (Holmer et al., 2002) given in table 2.

Table2. Share of nutrients in given feed as wet weight.

	Trash fish	*Formulated feed*
Nitrogen	4.42 %	5.03 %
Phosphorus	0.68 %	1.26 %
Carbon	19.30 %	43.83 %

The share of N, P and C lost with wasted feed was computed by subtracting the consumed feed from the total input of N, P and C to fit the balance of equation 9.

$$F_{Total} = F_{Wasted} + F_{Consumed} \qquad [9]$$

Figure 3 gives an impression of the numerical model setup that applies the mentioned equations to compute fish growth, survival and biomass curves, consumed feed and emissions of a batch of fish.

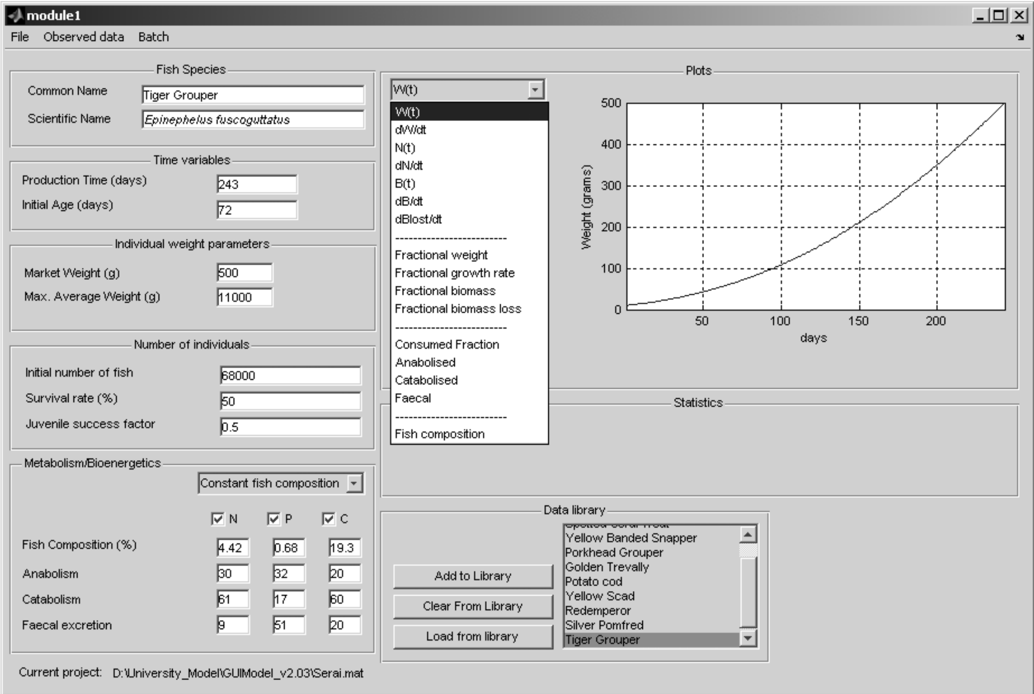

Figure 3 Mass balance fish growth model GUI.

Seed origin

The model distinguishes hatchery based aquaculture and capture based aquaculture. For hatchery based species it was assumed that a fish cohort was recruited at one point and then grows on, while the capture based species were assumed to be brought in evenly throughout the year by averaging the production over the modelled period.

3. Results

Total feed input in the Serai Area

Feed input for all cage clusters in the area lay around 82.6 ± 21 kg N/day, 13.1 ± 3 kg P/day and 349 ± 80 kg C/day. The feeding pattern follows a seasonal pattern, probably caused by external influences around monsoon seasons influencing fish wellbeing and mortality rates (Yung, Pers. Comm.).

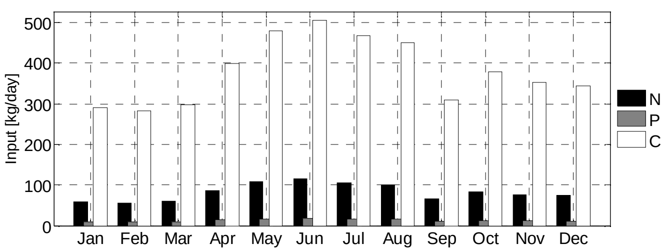

Figure 4: Input of N, P and C for the entire Serai area.

Computed feed conversion ratios in the Serai area

The FCR values of the model range from 4.8 to 7.4 throughout the year with an average of 6.0 ± 0.9.

The specific FCR's for N, P and C vary slightly from each other, averaging 6.0 ± 0.9, 6.2 ± 0.8 and 6.4 ± 0.7 respectively (figure 5) but follow the same pattern of the standard FCR throughout the year. According to the model there was a seasonal variation of feeding efficiency throughout the year, with high FCR during the periods May, June and November, coinciding with the feed input.

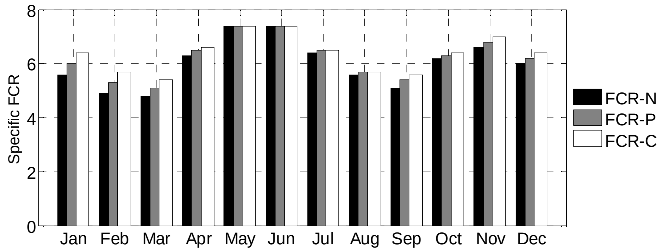

Figure 5: FCR-N, FCR-P and FCR-C throughout the modelled period.

Fish farm emissions in the entire area

For N and P emissions, wasted feed was the largest source. It was also the only emission that fluctuated according to the feed input. The retained amount (anabolism), respiration rate (catabolism) and faecal excretion were relatively constant throughout the year. For N, respiration was the dominant metabolic process (figure 6). Consumed P was mainly lost through faecal excretion (figure 7). Carbon respiration exceeds the amount of C lost through wasted feed (figure 8). The losses through mortality were the smallest.

Emission averages are shown in table 3.

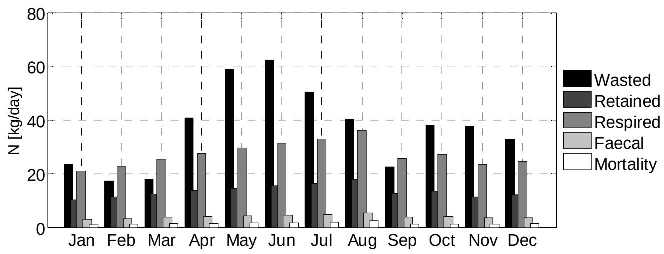

Figure 6: Retention and emission rates of nitrogen throughout the modelling period of all cage clusters within the Serai area.

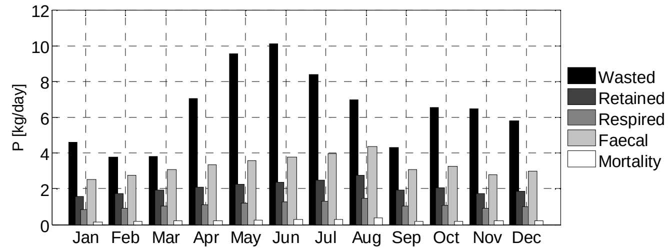

Figure 7: Retention and emission rates of phosphorus throughout the modelling period of all cage clusters within the Serai area.

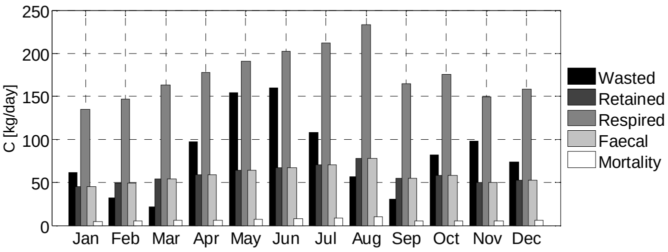

Figure 8: Retention and emission rates of carbon throughout the modelling period of all cage clusters within the Serai area.

Table 3: Averaged daily rates for growth and emissions, occurring in the entire area.

	kg N/d	kg P/d	kg C/d
Retained	13.43 ± 2.22	2.07 ± 0.34	58.63 ± 9.68
Respired	27.3 ± 4.51	1.10 ± 0.18	175.88 ± 29.0
Faecal	4.03 ± 0.66	3.29 ± 0.54	58.63 ± 9.68
Wasted	36.79 ± 15.07	6.45 ± 2.13	81.29 ± 45.2
Mortality	1.5 ± 0.4	0.23 ± 0.06	6.55 ± 1.76

Based on these results, the distribution of N, P and C in particulate and dissolved form can be displayed as a percentage of the total amount of given feed during the modelled period as shown in figure 9.

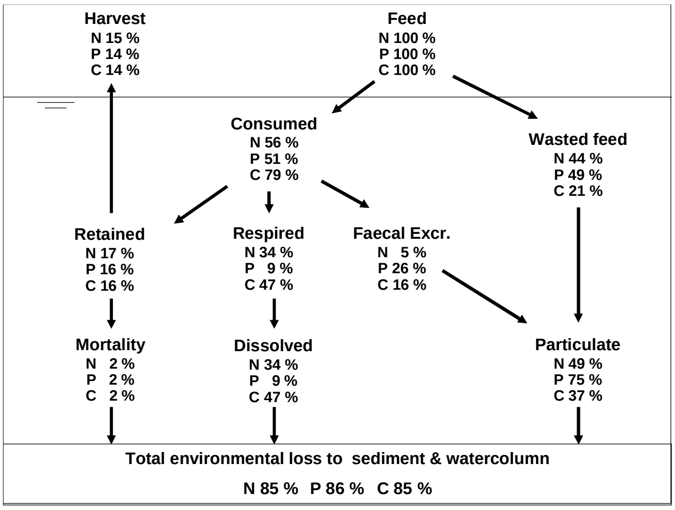

Figure 9: Feed distribution for N, P and C for the entire area, as an average of the entire modelled period.

4. Discussion

Model verification

Model results were compared to several studies available, at various sites which describe and quantify the distribution of given trash fish feed over the occurring processes based on measurements.

An important indicator is the feed conversion ratio. Previous studies indicated feed conversion ratios ranging from 4 to 9 according to Blyth and Dodd (2002), 6.5 according to Islam (2005) and Leung (1999), and 6.3 for trash fish and 5.5 for a mixture of trash fish and formulated feed (Santoso and Nursetiarso, 1999).

The model computed similar values, indicating that the biomass yield coincides with the given feed input.

According to the model, a major part of given N, P and C is lost to the environment. Table 4 shows the total feed input distribution of the model and those available from literature, taken from field measurements by Leung (1999) and Wu (1995).

These results indicate that the observed retention and emissions approach those of the studies.

Table 4: Modelled and measured emissions (Wu & Lueng) as a percentage of the total given feed.

		Retained	*Respired*	*Faecal*	*Wasted Feed*	*Total*
N	***Model***	**12 – 14 %**	**28 – 43 %**	**4 – 6 %**	**30 – 55 %**	**79 – 86 %**
	Wu					52 – 95 %
	Leung	12 %	46 %	4 %	38 %	88 %
P	***Model***	**14 – 20 %**	**7 – 10 %**	**22 – 31 %**	**39 – 58 %**	**80 – 86 %**
	Wu					85 %
C	***Model***	**15 – 19 %**	**40 – 56 %**	**13 – 19 %**	**7 – 33 %**	**80 – 81 %**
	Wu					80 – 88 %

Ladwig and Hesse (in preparation) investigated emission rates by means of field measurements at cage cluster II. This approach utilised flow rates through the cluster and temporal water quality measurements done during one day to estimate dissolved and particulate loads of N, P and C (Table 5).

Table 5: Model results compared with Ladwig and Hesse (in prep.) for cage cluster II, based on measurements taken in September.

	Dissolved		*Particulate*		*Total*	
	Model	*Ladwig (2006)*	*Model*	*Ladwig (2006)*	*Model*	*Ladwig (2006)*
Nitrogen	7.0 kg N/d	8.9 kg N/d	7.2 kg N/d	2.4 kg N/d	14.2 kg N/d	11.3 kg N/d
Phosphorus	0.3 kg P/d	0.6 kg P/d	2.0 kg P/d	3.3 kg P/d	2.3 kg P/d	3.9 kg P/d
Carbon	45.2 kg C/d	Not available	23.4 kg C/d	25.8 kg C/d		

The model results lie within the order of magnitude when it comes to the dissolved and total nitrogen emission, but varies greatly when considering particulate nitrogen while phosphorus emission is measured almost two times higher than the model predicted but their phase distribution lies well in range with the measured values. Carbon was only observed in its particulate form and fitted well with the model results. However, more calibration with different farms and fish species would be preferable to verify the reliability of this method.

Assumptions

There were several assumptions taken which simplified the complex processes occurring in and around cage fish farms and could influence model results.

The compositions of fish biomass was assumed to be fixed and metabolic processes were considered to take up fixed percentages of N, P and C of the consumed feed throughout the life stages of the fish. However, the processes of metabolism and the resulting fish biomass compositions may vary per species, life stage and feed type or quality (Masser, 1988)

Since growth curves are based on given target weights and grow out periods, water temperature does not play a significant role in the predicted growth rate of this model. Estimated mortality does not consider external influences such as, amongst others, turbidity, low dissolved oxygen syndrome or parasites which can cause fish stress and disease influencing this mortality rate (Masser, 1988). It was indicated by the fish farm management (Yung, 2005) that increased mortality occurs around monsoon seasons. These effects were not captured by the model and might affect fish numbers, biomass and metabolic ratios of the remaining fish and fish farm emissions.

Since the management of a fish farm can be quite complex where different types of feed are used, different species of various life stages are kept and where fish can come from different origin (hatchery or capture), a good insight in the farm management is crucial for describing the input parameters of the model. More detailed definitions of these recruited fish would improve model results.

Since these modelled emissions resemble a gross output, further analysis of hydrodynamic displacement and the acting biological processes are necessary to determine the holding capacity. Therefore mass balance model results should function as input into hydrodynamic water quality models.

Apart from nutrient discharges from fish farming activity, domestic inputs from the local settlement may add to the total anthropogenic nutrient load of the area. As it is usually the case in developing countries, the small village does not have any sewage treatment. Most nutrients are directly discharged as human waste into the shallow, nearshore area below the pile dwellings. Assuming per capita emission rates to be 7.6 – 7.9 g N/day, 1.6 – 1.7 g P/day and 76 - 79 g C/day per kg (Schouw et al., 2002) and considering the actual population size of ~ 136 people, it turns out that human excretion is responsible for an emission of 31.4 – 32.7 kg N/month, 6.6 – 7.0 kg P/month and 314.2 – 326.6 kg C/month. This discharge is, when considering the whole area, responsible for around 1 – 3 % of the total nutrient input. However, locally (200m radius) this load becomes more significant (4 – 8 %).

5. Acknowledgements

The present study was carried out as part of the SPICE project "Science for the Protection of Indonesian Coastal Environments" funded by the German Ministry of Education and Research under grant number 03F0393A. Responsibility of the content is with the authors. Cooperation with the IPB (Bogor Agricultural University) in Bogor/Indonesia and UNRI (Riau University) in Pekanbaru/Indonesia is very much appreciated.

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Evaluation of nutrient discharge and dispersion from a coastal fish farm in Indonesia

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Abstract

The discharge and distribution of particulate and dissolved nutrients (N, P) deriving from a traditional caged finfish farm situated in the Bintan archipelago was examined. Annual production of the farm amounted to 30 t of fish, most of which were groupers. Daily discharge of particulate organic nitrogen accounted for 2.4 kg N, whereas for dissolved nitrogen a daily load of 8.9 kg N was found. The bulk of dissolved organic nitrogen released (6.9 kg N) was made up of urea (4.8 kg N). Particulate phosphorus discharge accounted for 3.3 kg P/d, for dissolved inorganic phosphorus calculations resulted in a daily load of only 0.6 kg P. Particulate organic carbon was discharged at a rate of 25.8 kg C/d. Particulate nutrients rapidly decreased down to background values at the border of the fish farm construction indicating rapid sinking of the particles. However, no accumulation of particulate matter was observed on the sea bottom beneath the cages. This suggests a rapid dispersion of the particulate material due to the strong currents of > 1 m/s. A plume of enhanced dissolved nutrient concentrations and elevated BOD24 values was restricted to a distance of less than 200 m around the farm. Oxygen saturation during daytime generally exceeded 100% in the water column of the entire area. During the night period it dropped slightly down to 90%. There was no obvious effect of nutrient release on phytoplankton biomass as assessed by chlorophyll *a* measurements. This may be due to the high flushing rates in relation to phytoplankton doubling time. An approximation of the eutrophication status of the fish farm area using the TRIX method revealed that it was moderately eutrophicated. The holding capacity of the entire area for upscaling of fish farming activities was determined assuming that total nitrogen discharges from the fish farms have not to surpass a threshold of 1% of total hydrodynamic nitrogen flux. Despite the fact that nutrient discharges per kg of fish produced distinctly exceeded the HELCOM recommendations the holding capacity estimates would allow for an annual production of 3000 t of fish in the entire area.

Keywords

Marine aquaculture – nutrient discharge - eutrophication - Indonesia

1. Introduction

Indonesian fish production from mariculture was 420919 t in 2004 and shows a rapid increase over the last 10 years (DKP 2005). In contrast to fish farming in industrialised countries, which is often based on cutting edge technologies with automated feeding devices and formulated feed pellets, threshold countries such as Indonesia predominantly apply low-tec solutions with a comparably high amount of handcraft and trash fish as feed. Emissions from this kind of fish farming practice generally refer to nutrients more than to other pollutants such as antibiotics or antifouling paints. Especially under oligotrophic tropical conditions dissolved nitrogen and phosphorus compounds derived from excretion and feeding as well as particulate nutrients released as faeces and waste feed may lead to environmental deterioration. However, the response in terms of immission levels and subsequent ecological impact is not directly related to emission loads but mediated by the site specific hydrodynamic settings. Therefor, the critical load of fish farm operation has to be defined according to acceptable limits of nutrient enrichment in the region.

In the present study dissolved and particulate nutrient emissions (DIN, DON, urea, PON, PO4, PP, POC) from a traditional coastal cage fish farm in Indonesia were quantified and compared to the levels of nutrient enhancement and the occurrence of secondary effects in the surrounding sea area. Environmental sustainability with respect to nutrient enrichment was evaluated applying different modes of classification derived from various eutrophication assessment approaches.

2. Material and methods

Geography and hydrography

The study site is situated in the Riau archipelago (South China Sea) east of Sumatera between the islands of Siulung and Serai close to the Selat Telang (Strait of Telang), which is approximately 200 km southeast of Singapore (fig. 1). The investigated floating cage fish farm (Hiang Fishery Company) was installed on both sides of a narrow nautical channel between these two islands.

The channel is approximately 500 m long and 300 m broad with a maximum depth of 15 m and a coral barrier reef in 4 m depth at the western end. The bottom topography beneath the fish cages on the Siulung side of the channel shows steep gradients from 4-14 m depth within a distance of 30 m. The mixed dominant diurnal tides in combination with bottom topography result in strong currents of up to 1.3 m/s with an east to west direction during flood and vice versa during ebb tide. The fish cages represent a barrier in the flow which channelises and accelerates the tidal currents between cage bottom and slope.

Fig 1: Area of investigation and location of fish farm (white square).
(Source: Google Earth 2007)

Fish farm description and operation

The fish farm complex consists of floating rafts with nets fixed to the seafloor by ropes and anchors. It can be devided into eight groups of cages (clusters) of different size and fish stock. Measurements refer to the largest cage cluster at Siulung island. It consists of 112 individual fish cages with a size of 4x4x3 metres each, resulting in a total length of 120 metres, a width of 30 metres and an overall volume of 5000 m³. The multispecies breeding practice of the company encompasses about 10 cultured fish species. In the respective cage cluster the focus is mainly on the production of Tiger Grouper (*Epinephelus fuscoguttatus*), Potato Grouper (*Epinephelus tukula*), Yellow-banded Snapper (*Lutjanus adetii*) and Red Emperor (*Lutjanus sebae*) with an annual yield of about 30 t. The stock size in September 2005 accounted for 36000 fish with an overall wet weight of 9000 kg. Stocking is based either on fingerlings derived from a hatchery or on juvenile fish from wild catches. Feeding is done manually in the time span from 10:00h to 12:00h using mostly trash fish as feed. Only during periods of limited trash fish availability feed pellets are used.

Sampling strategy and analytical methods

In September 2005 hourly measurements close to the fish farm and in the channel between Siulung and Serai were conducted during the daylight period in combination with recurrent multiship surveys to investigate in the temporal and spatial distribution of dissolved and particulate nutrients, dissolved oxygen, chlorophyll *a* and suspended matter. The spatial survey covered a sea area of about 40 km^2 between the islands of Siulung, Mantang and Telang encompassing a high resolution sampling grid in the close vicinity of the fish farm site (1 km^2).

Measurements of current velocity and direction were conducted inside empty fish cages by means of a subsurface drifter. Vertical profiles of temperature, salinity, oxygen, chlorophyll and PAR light availability were obtained using a calibrated CTD-multiprobe (ME) equipped with a Clark cell (OxyGuard), a backscat fluorometer (Haardt) and a 4π-quantummeter (LiCor). In addition, water transparency was determined by Secchi disk readings. Daily cycles of in situ oxygen concentrations and saturation were measured using an optical stand alone probe (Hach).

Since CTD-profiles revealed that the water column was vertically mixed, the collection of discrete water samples with 5l-Niskin bottles was restricted to a 1 m-depth. For the analysis of chlorophyll, SPM and particulate nutrients (POC, PON, PP) subsamples were immediately filtered through Whatman GF/F filters. Filters were deep frozen (-20ºC) until further analysis in the German laboratory. For the determination of dissolved inorganic nutrients (NH4, NO2, NO3, PO4) and urea concentrations subsamples of the filtrate were preserved with mercury chloride (HgCl). For DON and DOP analysis another subsample of the filtrate was digested at 120ºC on-site using peroxodisulphate as oxidizer. All nutrient samples were stored in the dark.

Separate water samples were preserved for the determination of the biological oxygen demand in 24 hours (BOD24), which was done on the basis of Winkler titration (1888).

Chlorophyll *a* analysis was carried out using standard HPLC techniques. Suspended matter concentrations and loss on ignition (LOI, combusted at 550º C for 2 hours) were determined gravimetrically. Analysis for POC and PON was performed with an elemental analyser (Euro EA) following standard protocols on carbonate-free samples. Concentrations of particulate phosphorus and dissolved inorganic and organic nitrogen and phosphorus were determined according to Grasshoff et al. (1999).

Load calculation

Data was analysed by means of a t-test for significant differences between concentrations at the fish farm and in the channel. In order to calculate emissions (see equations below) which are discharged from the fish farm, in situ nutrient concentrations (C_f) were measured inside the fish farm starting at 9:00h in the morning until 17:00h. Local background values (C_b) derived from simultaneous measurements upstream in the channel were substracted from these data resulting in a remaining concentration (C_i) which can be attributed to the fish farm emission. Water flow-through (Q_i) was calculated from measured current velocities (V_i) inside the fish cages multiplied with the flow-through area ($A = 72$ m²). C_i at a specific time is than multiplied with the respective Q_i to determine the hourly load (L_i). L_i values were integrated over the eight hour period of measurements. In case of dissolved excretory nutrients (NH4, PO4 and urea) the resulting load (L) was multiplied by a factor of 3 to account for a daily discharge, assuming comparable daytime and nighttime release of dissolved phosphorus and nitrogen metabolic products by the excretory system of fish. By contrast, for particulate matter an additional nighttime faecal excretion is unneccessary to calculate, because release takes place until eight hours after feeding even for fish with a long intestinal tract (Sumagaysay-Chavoso 2003). Therefor, the measured particulate discharge over the eight hour period was taken as a daily load.

Eq. 1: $C_i = (C_f - C_b)$

Eq. 2: $Q_i = A \cdot V_i$

Eq. 3: $L_i = C_i \cdot Q_i$

Eq. 4: $L = L_{i=1} + L_{i=2} ...+ L_{i=8}$

where:

C_i = concentration for load calculation

C_f = concentration at fish farm

C_b = background concentration

Q_i = water flow-through at fish farm

A = flow-through area

V_i = current velocity

L_i = hourly load

L = daily load

3. Results

Dissolved nutrients

Marine tropical waters not subjected to freshwater input are usually oligotrophic. In accordance, the inorganic nitrogen concentration in the Selat Telang area is low. The tidal average of background concentrations of dissolved inorganic nitrogen accounted for 0.5 µM DIN, the bulk of which was attributed to ammonium (0.3 µM NH4-N). In contrast, the average ammonium concentration at the fish farm accounted for 1.0 µM NH4-N (tab. 1). Maxima for inorganic nitrogen components were 1.8 µM DIN-N including 1.5 µM NH4-N and generally occurred six hours after feeding. Ammonium represented about 20% of the total dissolved nitrogen released from the fish farm and summed up to 1.8 kg/d NH4-N.

Tab. 1: Maximum and average concentration of particulate and dissolved nutrient concentrations, suspended matter and loss of ignition at the fish farm compared to reference background levels. The last coulmn displays the calculated daily discharge from the farm.

		REFERENCE	FISH FARM		
parameter	**units**	**average**	**maximum**	**average**	**load**
					(kg/d)
DIN	(µM)	0.5	1.8	1.4	2.0
NH4	(µM)	0.3	1.5	1.0	1.8
DON	(µM)	8.9	20.3	13.8	6.9
Urea	(µM)	0.4	3.8	2.2	4.8
PO4	(µM)	0.03	0.3	0.15	0.6
SPM	(mg/l)	2.5	16.1	6.1	175.8
LOI	(mg/l)	0.9	4.9	1.9	66.8
POC	(µM)	15.2	59.6	47.8	25.8
PON	(µM)	1.5	5.6	4.2	2.4
PP	(µM)	1.8	8.3	3.9	3.3

With respect to dissolved organic nitrogen, high background values of 8.9 µM DON were observed which can be attributed to humic substances leaching from the mangroves. However, concentrations at the fish farm were by about 50% higher mounting to an average of 13.8 µM DON with a load of 6.9 kg/d DON the dissolved organic nitrogen shared almost 80% of the total dissolved nitrogen load.

As a part of DON, urea levels were investigated separately. Depending on the species and on environmental conditions, fish can excrete metabolic N-wastes as ammonium and urea. Even though most fish are described as ammoniotelic, mixed forms of ammonium and urea excretion are common, e.g. 75-90% of the nitrogen is released as ammonia and 5-15% as urea (Dosdat et al. 1996). The average urea concentration between the fish cages was 2.2 µM urea-N representing an increase of 500% when compared to the average background level of 0.4 µM. With a load of 4.8 kgN/d urea made up 70% of the total DON and represents twice much as NH4-N released from the fish farm.

The average dissolved inorganic phosphorus background concentration was 0.03 µM PO4-P. A mean concentration of 0.15 µM PO4-P at the farm site equals an increase of 500% in comparison to average background conditions in the channel. The daily phosphate load calculation reveals an emission of 0.6 kg PO4-P.

Measurements refer to a temporal restricted sampling period, i.e. eight hours during daylight. However, metabolism of fish requires time to release metabolic wastes through the excretory system. Sumagaysay-Chavoso (2003) detected two main peaks in excretion of the tropical milkfish (*Chanos chanos* Forsskal). The first peak of total ammonia nitrogen (TAN) and phosphate (PO4-P) excretion occurred 6 hours after feeding and the second 18-24 hours for TAN and 21 hours for PO4-P. Figure 2 supports these findings for the mixed aquaculture at the Siulung fish farm. An increase of urea (fig. 2 b) and ammonium loads (fig. 2 c) occurred 6 hours after feeding. For phosphate two peaks are visible: A first occurred 5 hours after feeding (15:00h - 16:00h) and a second in the morning 22 hours after feeding (fig. 2 d). In case of ammonium and urea a second peak in excretion was not covered by the measurement period.

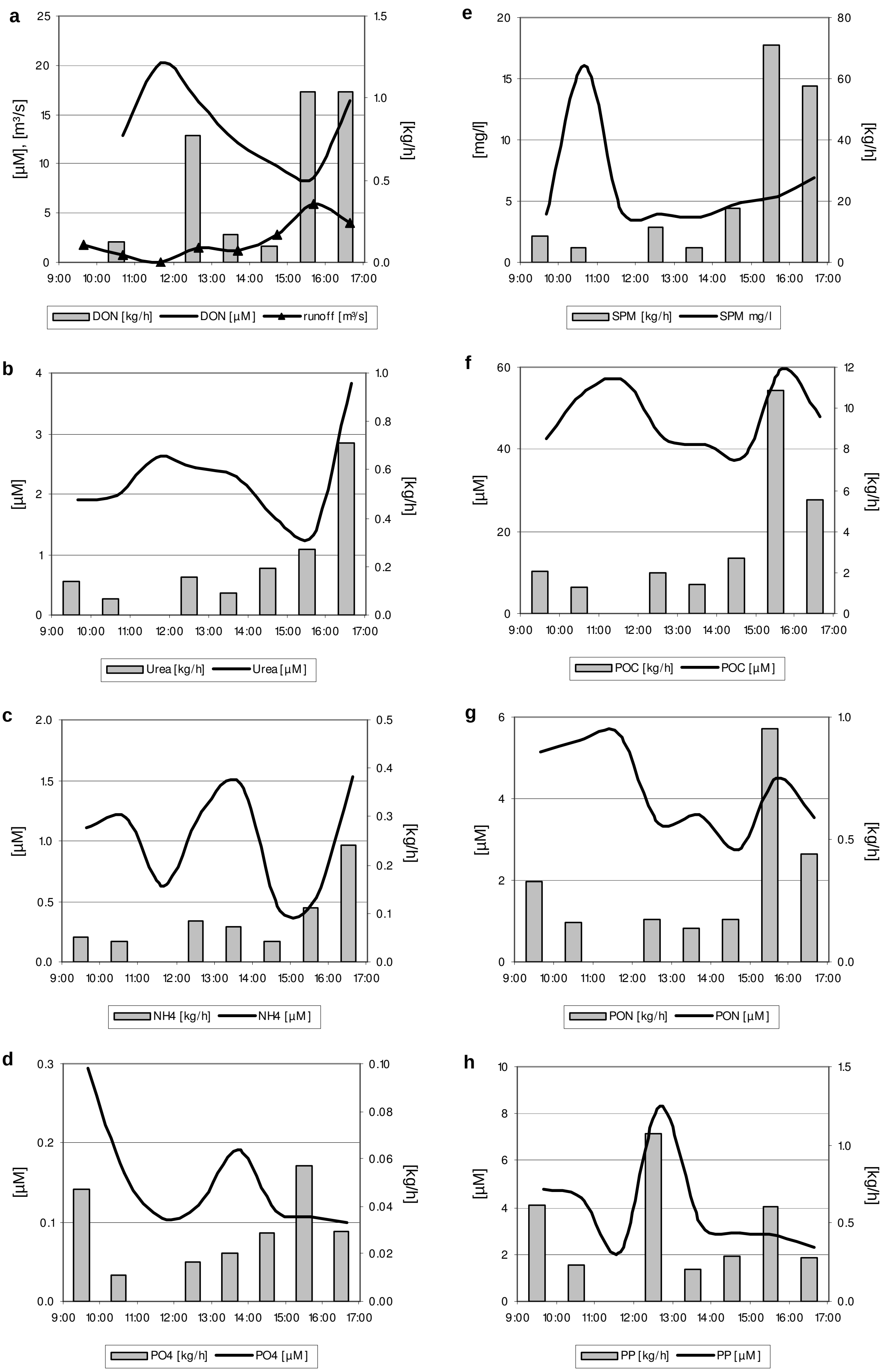

Fig. 2 a-h: Concentrations of dissolved nutrients (a-d) and particulate substances (e-h) as well as calculated hourly loads from the fish farm (flow-through indicated in diagram **a** as runoff).

Particulate matter

Compared to offshore tropical regions the waters between the islands of Siulung and Serai are rather turbid. The Secchi depth at a site in the central channel remote from the fish farm accounted for about 4.4 m in an average. By contrast, Secchi depth close to the fish cages decreased to only 2.4 m. The tidal average of suspended matter concentrations in the channel was 2.5 mg/l SPM (tab. 1). The mean loss on ignition (LOI) as an equivalent of organic matter content accounted for 0.9 mg/l. In keeping with the Secchi disk readings increased SPM values of 6.1 mg/l and a LOI of 1.9 mg/l were observed in the direct fish farm vicinity resulting in an average increase of a factor of 2 when compared to channel background values. Estimates of the suspended matter load from the fish cages resulted in 175.8 kg/d SPM and 66.8 kg/d LOI.

In accordance with the increased SPM loads near the fish cages, the particulate fractions of organic carbon (POC), organic nitrogen (PON) and phosphorus (PP) were distinctly higher at the farm site than in the channel. Average concentrations amounted to 47.8 µM POC, 4.2 µM PON and 3.9 µM PP which represent an increase of 315% for POC, 280% for PON and 217% for PP when compared to background concentrations (tab. 1). Calculation of the particulate nutrient load deriving from the cages yielded in a discharge of 25.8 kg/d POC, 2.4 kg/d PON and 3.3 kg PP per day. While loads of SPM (fig. 2 e), LOI, POC (fig. 2 f) and PON (fig. 2 g) were highest approximately 6 hours after feeding (15:00h -16:00h) the maximum PP load occurred around noon (fig. 2 h).

Comparison of calculated loads with model investigations

Balance model investigations for the fish farm based i.a. on production data and metabolic rates were carried out by Van der Wulp (this volume). Comparison of field and model data of particulate nutrient loads revealed that they are in a similar range (tab. 2). Model data for total particulate carbon discharge (TPC) from the farm accounted for 23.4 kg/d, thus constituting only a small deviation of about 10% when compared to field data of daily particulate organic carbon emissions (POC). This surplus may be due to the fact that the model also takes inorganic particulate carbon into account. Model data for total particulate nitrogen (TPN) accounted for 7.2 kg/d, 4.8 kg/d more than the PON load (2.4 kg/d) as assessed by the field measurements. Modelled loads of total particulate phosphorus (TPP) were 2.0 kg/d and thus 1.3 kg/d lower than the measured discharge of particulate phosphorus. However, it should be noted that, due to the applied methodology, measured particulate phosphorus loads (PP) include an undefined amount of particulate inorganic phosphorus. With respect to the dissolved fractions of nitrogen and phosphorus model calculations resulted in a discharge of 7.0 kg/d TDN and 0.3 kg/d TDP compared to field data of 8.9 kg/d TDN and 0.6 kg/d PO4-P measured.

In total the model and field data are in a quite good agreement when considering the rough assumptions made in both assessment methods (see also Van der Wulp, this volume). Moreover, model calculations were based on an entire production cycle resulting in average daily loads, whereas field measurements constituted a snapshot of a restricted time period.

Tab. 2: Comparison of calculated daily loads from the farm with model data (see van der Wulp, 2006).

FIELD		MODEL	
	(kg/d)	(kg/d)	
particulate			**particulate**
POC	**25.8**	**23.4**	TPC
PON	**2.4**	**7.2**	TPN
PP	**3.3**	**2.0**	TPP
dissolved			**dissolved**
TDN	**8.9**	**7.0**	TDN
DON	**6.9**		
Urea	**4.8**		
DIN	**2.0**		
NH4	**1.8**		
PO4	**0.6**		
		0.3	TDP

Spatial nutrient distribution

For most of the parameters a gradient in concentrations towards the farm site is visible. Immissions are not restricted to the vicinity of the fish farm, but the spatial distribution of dissolved nutrients in the channel follows the actual current pattern with highest values close to the fish cages (figs. 3 a-c). Levels of DON, DIN and PO4 increased by a factor of 2, 8 and 10, respectively, at the fish farm site when compared to the background concentrations.

The suspended matter distribution corresponds to the distribution of dissolved nutrients. SPM levels increased by a factor of 2 close to the western net border (fig. 4) and elevated concentrations extended in a plume reflecting the prevailing current direction during flood phase: water masses enter the channel from the eastern side and are enriched with dissolved and particulate matter when passing the fish farm. The distribution of particulate organic material (LOI) showed a strong similarity to that of SPM.

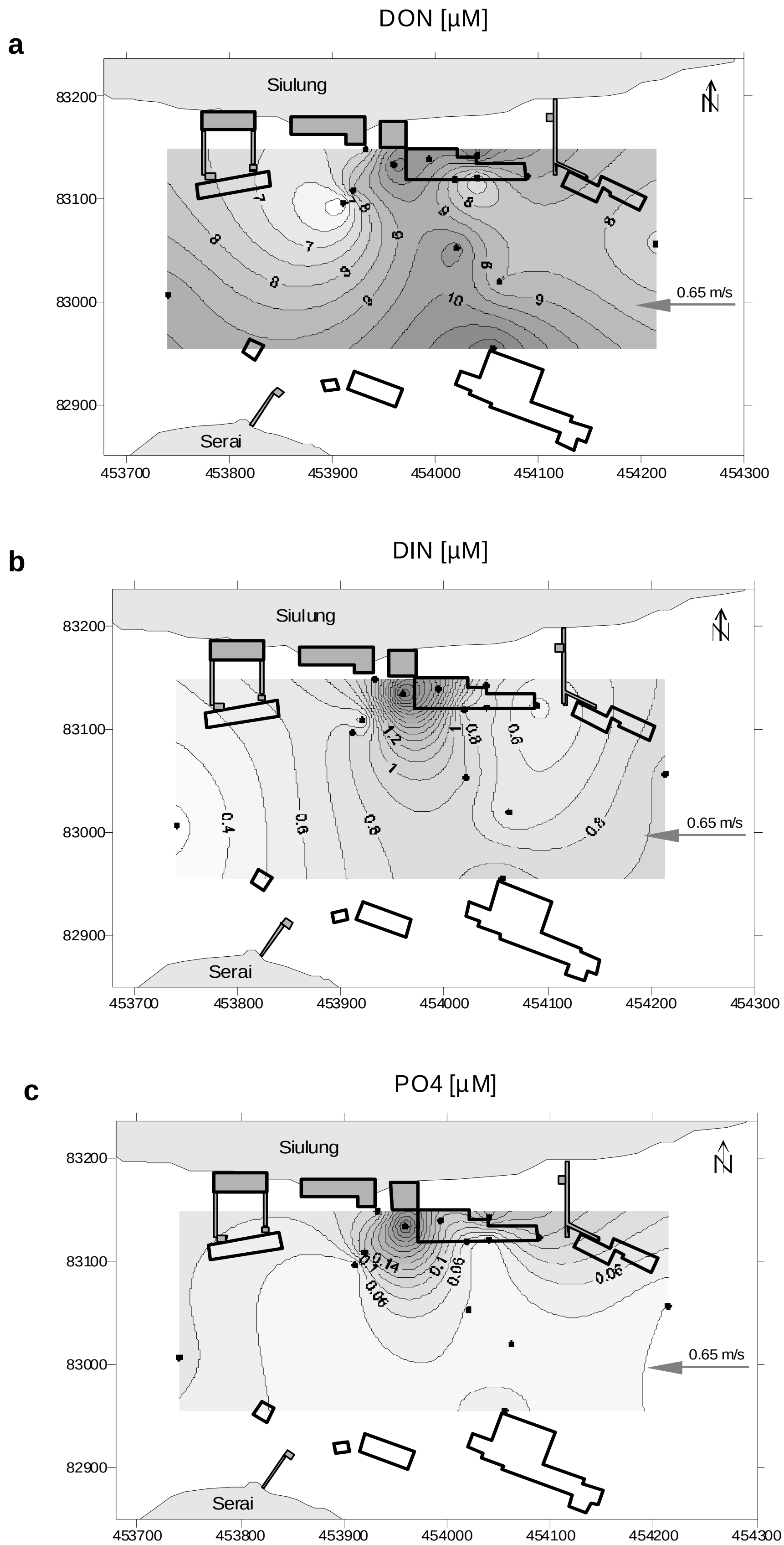

Fig. 3 a-c: Distribution of dissolved organic (a) and inorganic nitrogen (b) and phosphate (c) (cages indicated as transparent objects – cluster 2 is located in the centre close to Siulung).

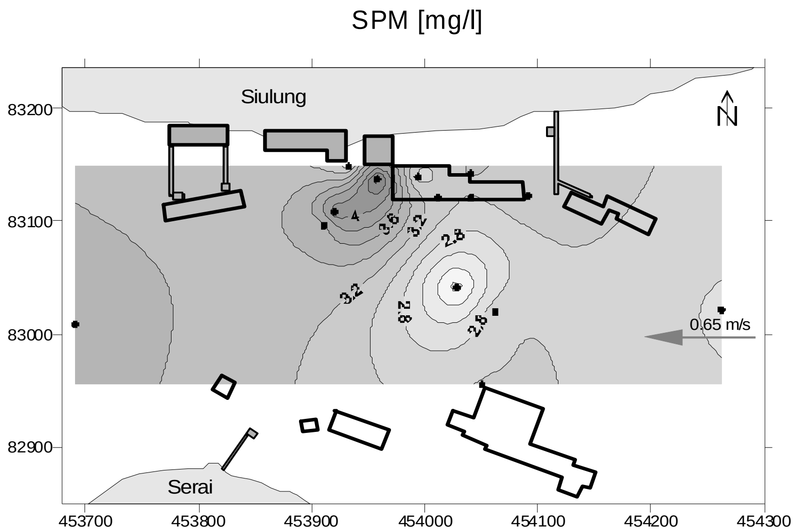

Fig. 4: Suspended matter dispersion between the islands of Siulung and Serai (average current speed in the channel indicated as arrow).

With respect to particulate organic carbon (POC), nitrogen (PON)and particulate phosphorus (PP) spatial maxima were restricted to the dimensions of the farm area itself which may be due to rapid sinking and grazing of these particles. A POC maximum amounting to 30 µM POC was observed at the net cleaning plattform where particulate matter is washed from the nets into the sea. POC concentrations decreased to local background concentrations of 11 µM POC at the western end of the cage cluster (fig. 5 a). The PON distribution showed a similar pattern with maximum levels of 4 µM PON at the net cleaning place whereas a rapid decrease down to 1 µM PON was observed at the edge of the fish farm (fig.5 b). These patterns suggest that the bulk of particulate nutrient emissions derives from the net cleaning process, however rapid sedimentation or grazing prevents the dispersion of the particulate material. For particulate phosphorus, gradients show a slightly different picture (fig. 5 c). Two maxima of 4.3 µM PP and 4.8 µM PP were located in the center and at the southern border of the cage farm.

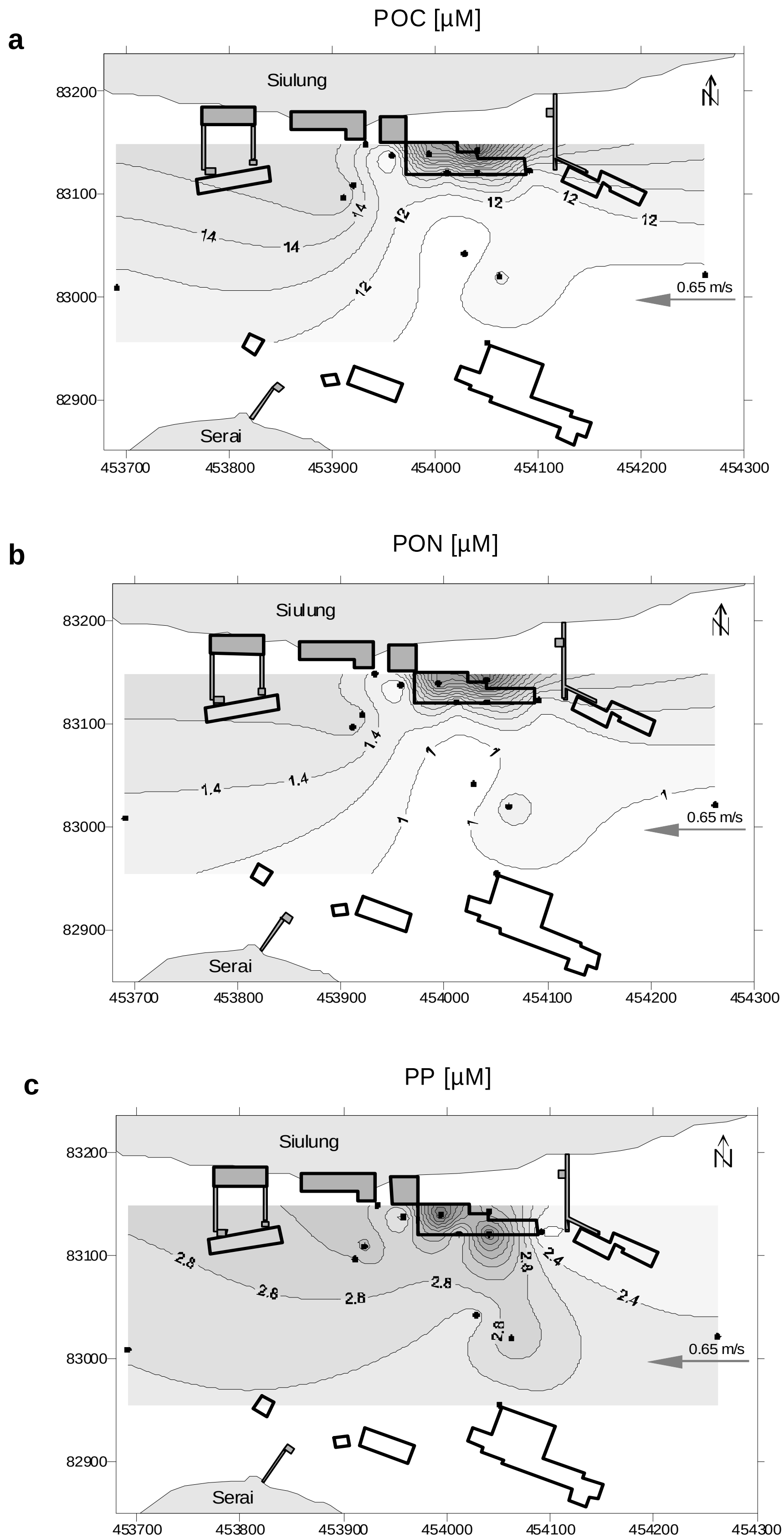

Fig. 5 a-c: Distribution of particulate organic carbon (a) and nitrogen (b) and particulate phosphorus (c) in the fish farm area.

Biological effects in the pelagic environment

Biological oxygen demand

As an immediate consequence of the availabilty of degradable material released from the farm the biological oxygen demand (BOD) in the vicinity of the fish cages increased. However, it should be kept in mind that the samples were incubated in closed water bottles and that the measurements thus do not reflect the in situ oxygen consumption. Considering natural in situ conditions of the area which is characterised by average current speeds of more than 60 cm/s it is likely that the bacterial decomposition process of organic matter is much slower than the fast removal of organic matter. Therefor, the BOD is rather a proxy for the organic matter content than of the in situ oxygen consumption. This is confirmed by the similarity in the distribution of BOD and particulate organic carbon. Inside the fish farm the biological oxygen demand in 24 hours (BOD24) was 1.0 mg/l. It rapidly decreased towards the middle of the channel (fig. 6). Assuming a stoichiometric ratio of oxygen to carbon (O:C) of 2 and a respiratory quotient (RQ) of 0.7-1.0 (Parsons et al. 1977), the BOD24 at the farm equals a carbon demand of 0.26-0.38 mg/l in 24 hours.

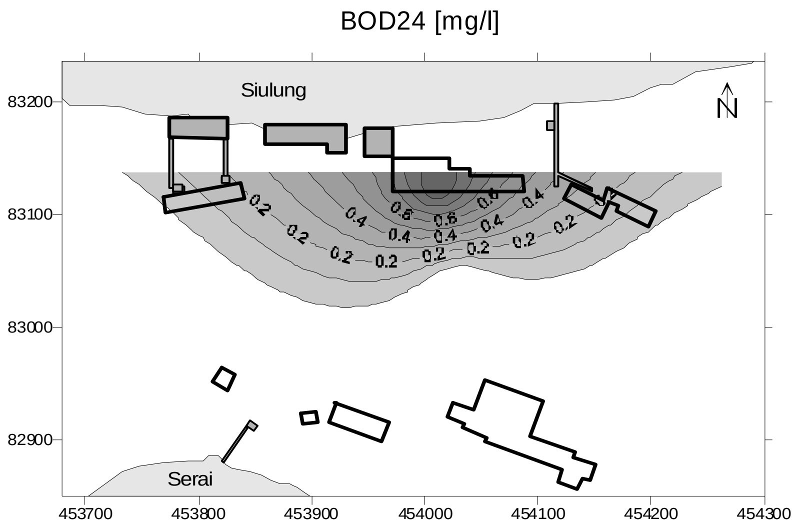

Fig. 6: Pattern of the biological oxygen demand (BOD24) around the fish farm.

Oxygen availability for in situ degradation of organic matter was almost constant above the 100% saturation level in the entire area around the fish farm (fig. 7). This referred to the entire water column during daytime whereas during the night period only a minor decrease to 90% saturation was observed in a depth of 1 m below the sea surface. The low pelagic chlorophyll *a* concentrations (< 0.5 µg/l) and the persisting high oxygen levels in the deep water suggest that benthic net photosynthesis constitutes a main oxygen source in the area. One reason may be the net oxygen production by zooxanthellae from the abundant coral communities in the region.

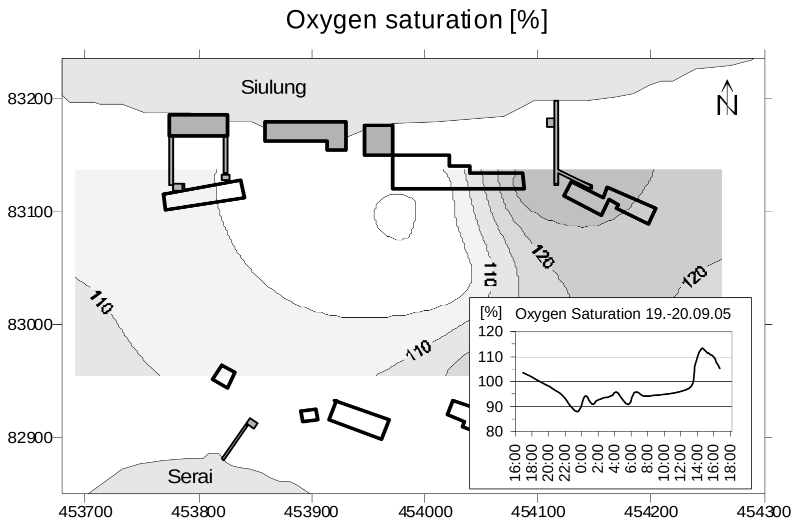

Fig. 7: Oxygen saturation between the islands of Siulung and Serai during daytime and diurnal variation at the fish farm (insert).

From current measurements inside the fish farm a daily water flow-through of 54.3 m³/d can be deduced. This volume of water has a daily carbon degradation capacity of 14.1-20.6 g C/d compared to a load of 25.8 kg POC/d (see above). Part of this organic material will be decomposed in the water column in the direct vicinity of the fish farm whereas another fraction will be subjected to sedimentation.

Phytoplankton and light availability

Intense PAR radiation of more than 2000 µmol/m²s penetrates the sea surface at noon. In a 10 m depth a light availability of 75 µmol/m²s was still observed, resulting in an attenuation coefficient of 0.33/m and an euphotic zone depth of 14 m. Considering the maximum water depth of 15 m in the channel an average light intensity of 400 µmol/m²s PAR is available for phytoplankton photosynthesis in the vertically mixed water column. Generally, light compensation intensities of marine phytoplankton are well below this value (e.g. Falkowski & Owens 1978). Light supply is thus sufficient for net primary production. However, chlorophyll *a* concentrations as a proxy for phytoplankton biomass were low. They accounted for 0.1-0.5 µg/l and revealed an undifferentiated spatial pattern without any increase in the fish farm vicinity. Vertical variability of chlorophyll *a* as measured with a backscat fluorometer usually ranged between 0.1 and 0.3 µg/l. HPLC pigment analysis (fig. 8) revealed the parallel occurrence of the pigments fucoxanthin and diadinoxanthin sometimes in conjunction with zeaxanthin, indicating that the autotrophic plankton mainly consisted of diatoms (bacillariophyceae) and small amounts of cyanophyceae. As it is the case for many tropical seas, phytoplankton growth was obviously nutrient limited. Background concentrations of dissolved nitrogen and phosphorus were in the range of nutrient limitation, whereas silicate was plenty enough. However, it cannot be deduced from the data set whether nitrogen or phosphorus was the main limiting nutrient species.

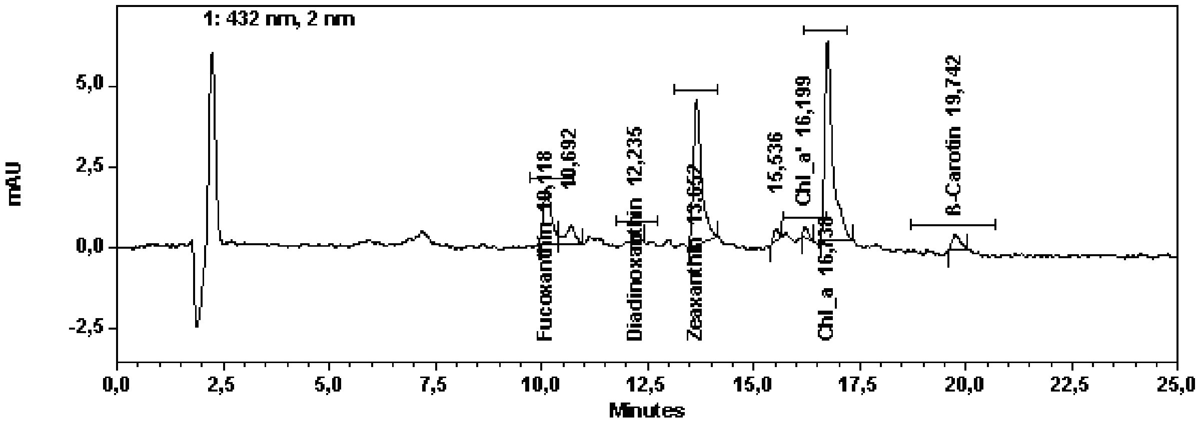

Fig. 8: Pigment composition of the phytoplankton community in the area of investigation.

5. Discussion

Sources and pathways for particulate matter

Particulate emissions can be attributed to different sources in the operation of a fish farm. Especially when trash fish is fed pronounced amounts of feed are lost to the environment. Other particulates are due to the excretory products released as faeces. Net cleaning from fouling may be another important source of solid emissions. At the Siulung fish farm this is realised via steam blasting on a swimming plattform. The isoline pattern of particulate and dissolved nutrients in the fish farm area are a hint for the fate of the substances. While dissolved nutrients are subject to advection in the surface water, the emitted organic particles (POC, PON, PP) tend to sink to the deep water which is reflected by the rapid decrease of concentrations beyond the fish farm itself. However, no accumulation of sedimentated particles has been observed underneath the cages (Runte, pers. comm.). This implicates that the particulate matter derived from the fish cages is subject to intense advective transport near the bottom and/or dispersed over a wide area. In fact, strong currents exceeding 1 m/s were observed underneath the cage constructions which is due to a hydraulic jet in between the cage and the sea bottom. It can thus be suggested that a detioration of the sediment due to the emission of particulate material from the fish farm is prevented by the hydrodynamic characteristics of the area. This is confirmed by the high oxygen saturation levels in the bottom water.

Phytoplankton reactions and nutrient availability

When compared to light compensation intensities of marine phytoplankton, the average underwater light intensity in the Siulung area does not constitute a limiting factor for phytoplankton primary production. In turn, low nutrient background values and low chlorophyll *a* concentrations indicate that primary production is nutrient limited. Additional nutrient supply might than stimulate phytoplankton growth especially with respect to the outstanding light supply.

The bulk of total dissolved nitrogen discharge from the fish farm under study was made up of dissolved organic nitrogen (DON). Generally, DON can represent a large part of the total dissolved nitrogen pool especially in regions which are supposed to be nitrogen-limited. Besides refractory humic and fulvic acids which may constitute 40-80% of DON (Alberts & Takács 1999), highly labile fractions of urea and dissolved free amino acids belong to the DON pool. They are preferably taken up by some phytoplankton species and hence have fast turnover times from minutes to days (Bronk et al. 2006).

The urea fraction of the nitrogenous waste derived from the fish farm was much higher (factor 2.7) than the released NH4-N fraction. When compared to other studies (Dosdat et al. 1996, Handy & Poxton 1993, Kaushik & Cowey 1991) this value is extremely high. Anyhow, it shows that the importance of urea as relevant source of pollution should not be underestimated.

From the data no obvious increase in phytoplankton biomass was observed in the vicinity of the fishfarm despite of the higher availability of dissolved nitrogen and phosphorus. The plume of enhanced nutrient concentrations was limited to a distance of less than 200 m. Considering the median current velocity of 0.65 m/s a water body needs about 5 minutes to leave this area. Phytoplankton cell division, however, is in the order of days, i.e. in the present case the flushing rate is much faster than phytoplankton generation time. In contrast, fish farming areas exhibiting long residence times in combination with calm weather conditions may be affected by nutrient stimulated HABs as observed in the Bolinao area, Phillipines (Holmer et al. 2003). Hence, hydrodynamics are of primary importance in a suitable site selection for the implementation and operation of marine fish farms (Windupranata, 2007).

Evaluation of the eutrophication status and the holding capacity of the area

Classification of the eutrophication status

A comparative calculation of the Trophic Index (TRIX) after Vollenweider et al. (1998) was carried out using the averaged data of one sampling station at the fish farm and another in the channel. The following equation was applied:

Eq. 5: $TRIX = (\log_{10} [chl \times aD\%O \times TN \times TP] + k) / m$

where:

chl = chlorophyll *a* concentration [µg/l]

aD%O = absolute deviation from oxygen saturation [%]

TN = total nitrogen concentration [µg/l]

TP = total phosphorus concentration [µg/l]

k = 1.5

m = 1.2

The parameters k and m are to determine the lower limit of the index and the extension of the scale (0-10). Total nitrogen and phosphorus concentrations incorporate dissolved inorganic (DIN, PO4), organic (DON, DOP) and particulate (PON, PP) compounds. For the fish farm a TRIX value of 4.8 and in the channel a value of 4.4 were found (tab. 3). According to Giovanardi & Vollenweider (2004) values lower than 4 TRIX units are associated with scarcely productive coastal waters whereas values exceeding 6 TRIX units are representative for highly productive coastal waters. It thus follows that the region under investigation can be characterised as a moderate productive area with the waters at the fish farm itself taking an intermediate position.

Tab. 3: Data applied for the calculation of the Trophic Index (TRIX).

	Reference	**Fish farm**	**Units**
chl	0.2	0.2	[µg/l]
aDO2%	2	2	[%]
TN	150	271	[µg/l]
TP	103	169	[µg/l]
k	1.5	1.5	[-]
m	1.2	1.2	[-]
TRIX	**4.4**	**4.8**	[-]

Determination of the holding capacity

The maximum holding capacity of the entire area for the upscaling of fish farming activities has been determined by water quality modelling on the basis of nutrient emissions from the farm and an allowable nutrient enhancement of 50% above background concentrations (Özgürel, this volume). The model calculations resulted in an allowable expansion of fish farm activities by 60 cage clusters equivalent to a stock size of 400 t of fish corresponding to an annual production of about 1400 t.

A more simple approach to estimate the holding capacity of a defined area for sustainable fish farm activities is based on the assumption that nitrogen emissions must not surpass 1% of the total nitrogen flux through the area. The nitrogen flux was calculated on the basis of hydrodynamic model data on net water transports (Windupranata, pers. comm.) and total nitrogen concentrations at the boundaries of the area. The net volume of water transport accounted for 8200 m^3/s, resulting in a total nitrogen flux of about 104000 kg TN/d. The total nitrogen discharge from the fish farm under investigation (11.3 kg TN/d) represents only 0.01% of the total flux through the area, maximum tolerable emission can thus be increased by a factor of 100. Considering the average production of the fish farm amounting to 30 t per year (Van der Wulp, 2006) it follows that fish production in the area can be upscaled to 3000 t. This constitutes about two times more than the maximum holding capacity as derived from the water quality modelling. It is of note, however, that in the model simulations the fish farm cages were placed in a small stripe along the coastline which was designed as suitable for nearshore cage farming, whereas in the simple approach the entire area was assumed to be suitable for fish farming.

Recommendations from HELCOM (2004) stated that nutrient discharges from fish farming should not exceed the annual average of 50 g TN and 7 g TP per kg (living weight) of fish produced. For the fish farm under investigation a nutrient discharge of 145 g TN and 47 g TP per kg of fish produced was estimated on the basis of field data on nutrient emission. Taking model data as a basis (Van der Wulp 2006) a discharge of 219 g TN and 35 g TP per kg fish produced was calculated. These emissions do not meet the HELCOM recommendations. One reason may be the large amounts of trash fish used as feed. Reduction of the per kg discharge would allow for a distinctly higher holding capacity for fish farming activities in the area.

Acknowledgements

The present study was carried out as part of the SPICE project "Science for the Protection of Indonesian Coastal Environments" funded by the German Ministry of Education and

Research under grant number 03F0393A. Responsibility of the content is with the authors. We appreciate the skillfull assistance of Ms. Daniela Koch in sample processing and analysis.

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Suspended matter fluxes and depositional processes in the cage finfish farm Siulung Riau Archipelago, Indonesia.

Katharina Róisín Niederndorfer & Karl-Heinz Runte

1. Introduction

Large areas of the Indonesian coastal seas are tropical oligotrophic ecosystems threatened by human effluents, waste discharge and environmental destruction. There is a common concern that the tearing growth of aquaculture activities in Indonesia may increasingly contributes to worsen this problem. Despite of progress in developing and establishing regulations for sustainable fish farming the effluents released remain subjects of attention. While assessing the deterioration risks, quality and quantity of matter released, dispersion, transport, settling and degradation are decisive parameters to be taken into account.

There is broad consent that the exceed of critical levels of excrements and waste food released from fish farms initiate disturbances in vital processes of marine ecosystems according to their specific sensitivities and trophic states (Krom & Neori 1989, Seymour & Bergheim 1991, Brown et al. 1987, Rosenthal 1994, Pereira et al. 2004, Porello et al. 2005). The food conversation rate is a significant magnitude that also indicates the metabolic losses of nutrients to the environment. Wu (1995) found that ca. 85%P, 80-88%C and 52-95%N taken up in food are emitted by respiration, excretion and as waste food. Computing conversion rates in salmon farms in Michigan/USA, Ramseyer et al. (1997) underline that only 30% of N and P as food compound contribute to fish growth even if food is entirely taken up. Hall et al. (1990) report from a marine trout farm in Sweden that 75-78%C offered in food get lost to the marine environment and about 18%C offered is estimated to accumulate on the sea floor in longer time scales. In a comparable context Holby & Hall (1991) observed that 78-82%P offered in food is released, of which 59-66%P accumulate in the sea floor sediments. Although considerable improvements of food conversation rates were achieved in the meanwhile, a fish farm remains a “hot spot” (point source) of nutrients endangering the sediment quality in local and regional scales. Studies describe decreasing concentration of organics released with increasing distance from fish farms (Gowen & Bradbury 1987, Hall et al. 1990, Angel et al. 1995, Schendel et al. 2004). Wu (1995) declares the area of impact of fish farms on the sea floor to be limited to about 1km around the farms. Aguado-Gimenez & Garcià-Garcià (2004), however, found enhancements with increasing distance and explain external sources of nutrients to be responsible.

It is remarkable that the complexity of hydrological and depositional processes many fish farm areas are exposed to is mostly marginally considered. There are still uncertainties concerning the tying links between the waste released and the sediment quality in fish farm areas involving the specific hydrodynamics, topographic features and the depositional environment in terms of sediment dynamics, sediment composition and matter supply. The presented investigation particularly aims to investigate the matter flux towards the sea floor and to consider the relationship between farm positioning and sediment quality according to the hydrodynamic environment exemplarily found at the fish farm “Hiang Fisheries” close to Bintan, Riau Archipelago, Indonesia. The following topics are discussed

1. Is the organic flux to the sea floor an adequate criterion to infer the deterioration of the sediment quality under a fish farm?
2. Are there confidential relationships between suspended matter and the sediment composition?
3. Which effects may blur the waste flux to the sea floor?

The activities involved were carried out in the project “Development of a Decision Support System for the Sustainable Management of Coastal Living Resources“ which contributes to the framing SPICE-Project (Science for the Protection of Indonesian Coastal Ecosystems). We thank the German BMBF, the Universities of Bogor (Java), the University of Riau (Sumatra) and the cooperating authorities in Indonesia for their support.

2. Area of Investigation

The considered cage fish farm *"Hiang Fisheries"* is located close to Bintan, Riau Archipelago, Indonesia (Figure 1). It essentially consists of two clusters of floating cages positioned in a tidal channel between the neighbouring islands Siulung and Serai. The mean tidal rage is about 2m. A profile starting at the coastline of Siulung crosses a shallow and widely destructed coral reef platform falling dry at low tide which moderately slopes over 50-300m towards a bordering coral reef rim that marks the water line at low tide. From the reef rim the profile quickly drops down towards a broad tidal channel that separates Siulung and Serai. The channel's width locally varies between 200-300m and the water depths in the central deeps ranges between 7m and 14m.

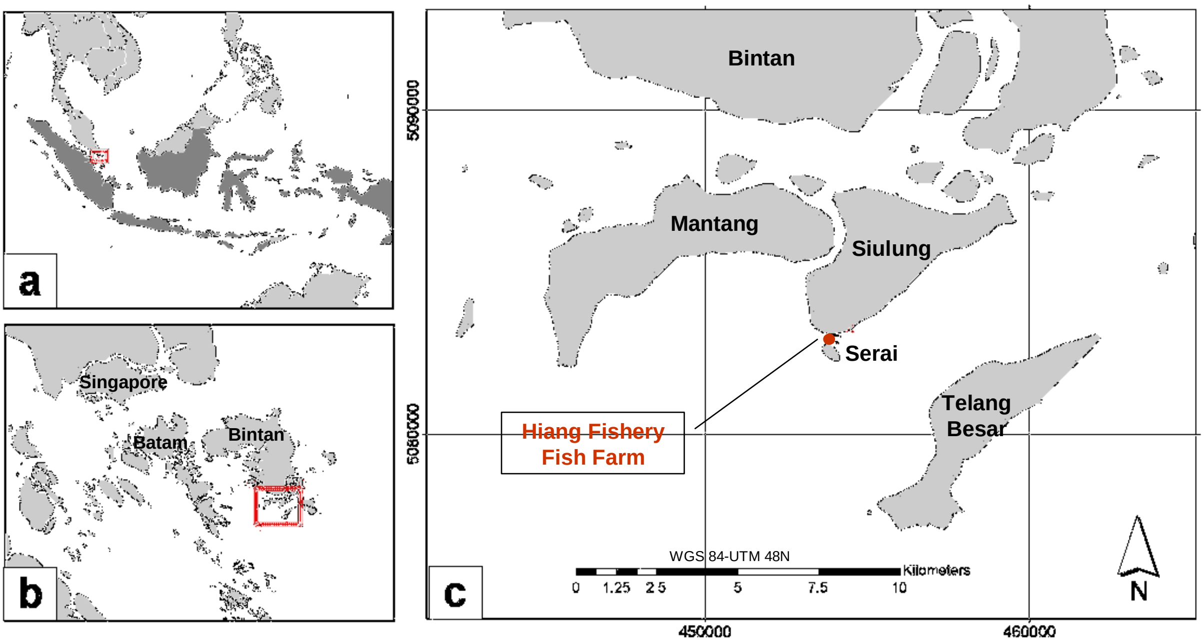


Figure 1: Study area. Indonesia (a), Riau Archipelago (b) and Hiang Fishery Fish Farm (c)

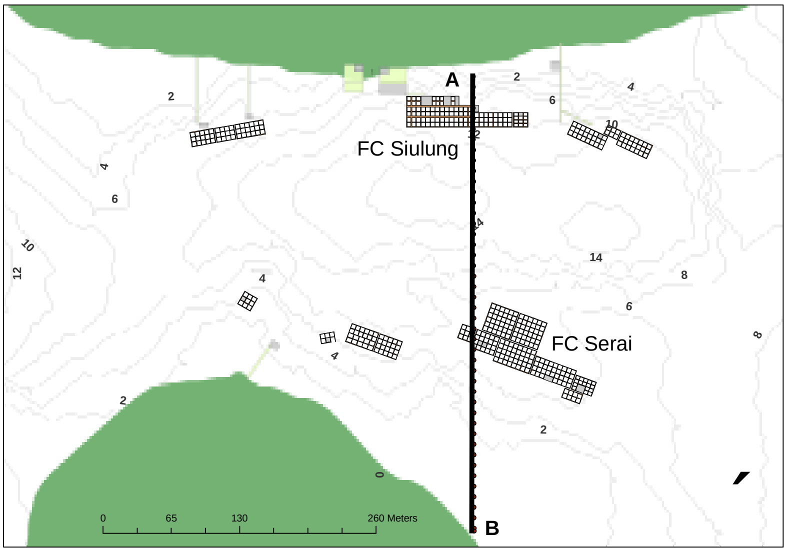
3. Farm operation

Finfish mariculture at Siulung started in 1979. At first culturing of fish was carried out for satisfying personal needs. Later the farming facilities stepwise expanded to more than 300 cages. Locals operate another 190 cages for their own business. A village is associated to the farm. Houses and cabins are established on wooden stilts founded in the tidal flats. Along the inhabited coastal sections the mangrove forest has been destructed to ensure the free access to the sea. Domestic effluents released are dispersed and moved away by tidal currents.

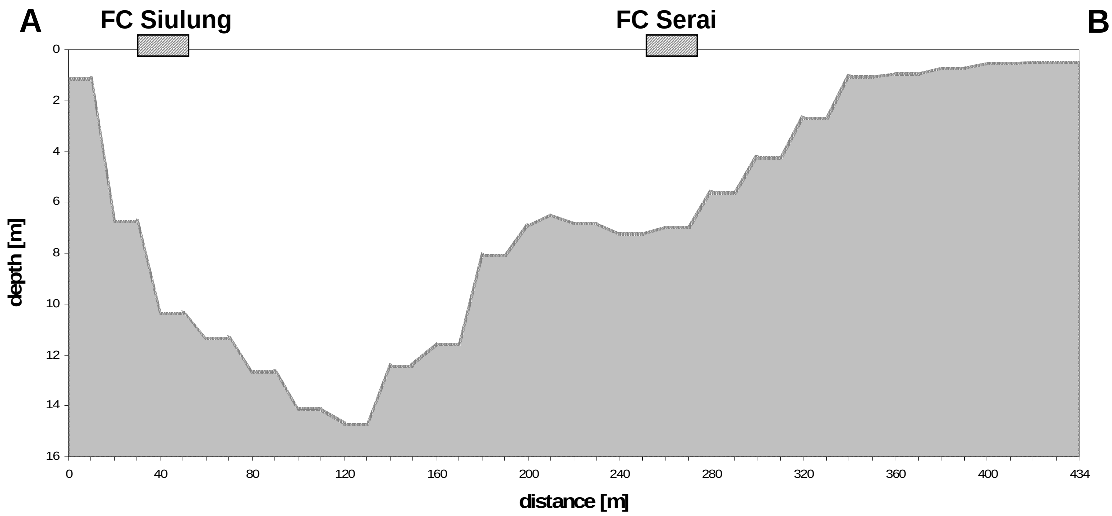
The fish cages are rectangular constructions of wooden frames each carrying a net of 4m x 4m x 3m volume. The cages are arranged to clusters and are kept afloat on large plastic drums (Figure 2). Heavy ropes anchored on the sea floor fix the position of the clusters in the tidal flow. FC (Farm Cluster) Siulung and FC Serai each comprise 112 cages and 197 cages, respectively. Fingerlings for culturing are purchased in hatcheries in Singapore while other fish is captured from the wild for being reared in the farm to market size. FC Siulung and FC Serai yield 30.5t and 47.5t fish per year, respectively (Wulp van der, 2006).

Figure 2: Fish farm cages close to Siulung

As indicated in Figure 3 FC Siulung is located just over the bed slope toward the tidal channel. The second cluster, FC Serai, is established more southward in the channel close to Serai.



(a)



(b)

Figure 3: Fish farm clusters at Hiang Fishery Fish Farm (a) and depth profile below the clusters Silung and Serai (b)

The cultured fish is fed with trash fish captured by local trawlers. The supply of the farm with trash fish varies over the year, so that food pellets are fed if the supply drops below the demand. In general, feeding is performed manually once a day at 10am, whereas younger fish stocks are fed several times over the day. While feeding, the excited fish tear the food to small pieces and scuba divers could observe clouds of food particles passing the nets, slowly dispersing in the tidal flow and sinking to the sea floor.

4. Measurements

Sampling of suspended sediments

The physical properties of the fluid, the grain size and falling velocity as well as the lateral flow off-set are essential magnitudes in the deposition process of suspended matter. Turbulences may significantly complicate this process. In the tidal cycle the (gravity) settling of suspended matter is in general restricted to periods of low water movement close to high tide and low tide water levels. In the time intervals between high tide and low tide the tidal currents prevent the settling of suspended matter and may even remove sediments off the sea floor if they exceed the critical shear velocity.

To estimate the particle fluxes between the fish cages and the sea floor sediment traps were deployed at several locations and water depths at FC Siulung. A specific arrangement of the traps aimed to deliver horizontal and vertical variances of the matter fluxes between the farm cages and the sloped sea floor between the coral reef platform and the adjacent tidal channel.
The sediment traps, represented by PE containers (30cm length and 5cm opening), were installed across the fish farm Siulung at the locations St1 (Siulung trap 1), St2, St3 (Figure 6). At each location a trap cluster consisting of 3 units vertically attached to a rope was positioned in 4m, 6m and 8m water depths, respectively (Figure 4). The upper end of the rope was attached to the wooden catwalk over the narrow gaps between the cages. A heavy weight at the lower end of the rope kept the system vertically stretched Figure 5. The arrangement ensured the distance of the trap units relative to the bottom of the net cages (in 3m water depth) to stay uniform, while the distances of traps and cages to the sea floor would vary within the tidal cycle.
While the traps were installed in the water column, we refrained from positioning sediment traps directly on the sea floor to prevent the traps to trigger scouring and resuspension of sediment in the tidal flow.

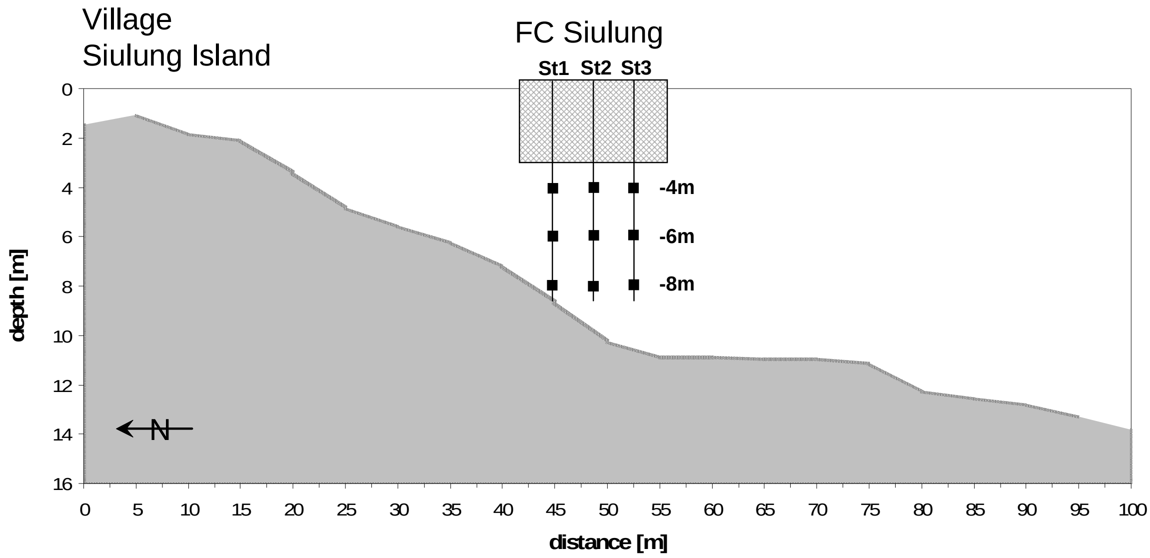
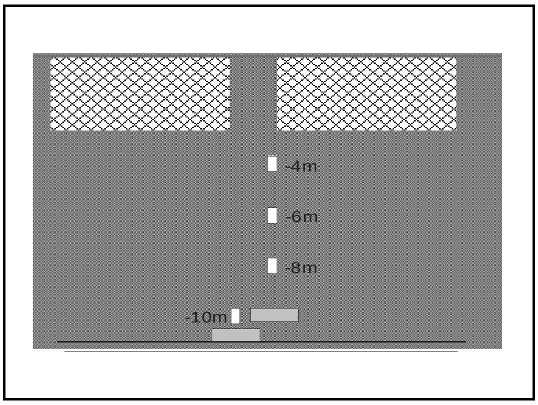


Figure 4: Sediment traps set-up below FC Silung

FC Siulung (St1, St2 and St3) (10m trap during continuous exposure)



Reference (REF2)

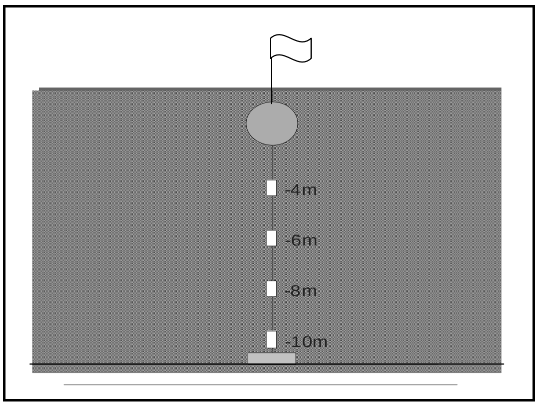


Figure 5: Design of the sediment trap sampling stations

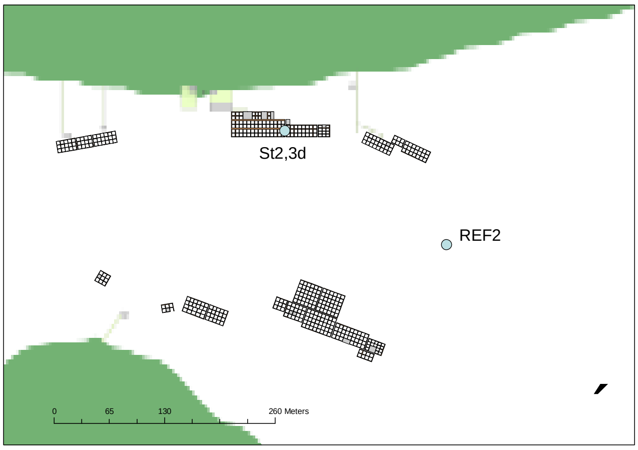
From Sep19 to Sep22, 2005 the sediment traps were daily sampled between 15:00 and 15:30pm. Ropes and attached traps were slowly lifted to the water surface where the traps were locked. In the field laboratory the traps were left standing for ca. 2 hours. Then they were carefully decanted into smaller PE containers. A small additive of HgCl prevented the bio-decomposition of organic compounds. At Kiel University the samples were repeatedly treated with distillate water, centrifuged and decanted (HERAEUS SPATECH Cryofuge 5000 and HERAEUS CHRIST Varifuge GL). The samples were filled into pre-weighed plastic beakers (100 ml) for freeze-drying and finally weighted. The resulting weight of matter (and its carbon content) per time, per location, per water depth and per deposition area was considered as *Depth related Depositions Rate* (DDR_d) [g/m²/day], calculated by applying equation 1.

$$DDR_d = \frac{c}{\left(\frac{D}{2}\right)^2 \cdot \pi} \qquad (1)$$

DDR_d	Depth related Deposition Rate of matter (and organic carbon) [g/m²/day] at the water depth d
c	Daily-averaged accumulation of matter (and organic carbon) in the suspended sediment traps [g/day]
D	Diameter of the trap's opening [m]

The second sampling of suspended matter between Sep22 and Sep25, 2005 aimed to investigate similarities and unconformities of DDR_d between FC Siulung and a remote station (REF2) located ca. 250m SE of FC Siulung (Figure 6). Two trap clusters, each consisting of 4 sediment traps in 4m, 6m, 8m and 10m water depth, were exposed for 3 days at the locations St2 (FC Siulung) and REF2, respectively. After 3 days exposure the samples were yielded.

a)



b)

Figure 6: Locations of the sampling stations at FC Siulung (a) and location of the reference station (REF2) (b)

Sampling of sea floor sediments

Sediments are generally conservative indicators of the deposition processes. The *Sea Floor related Deposition Rate* (SFDR) was estimated by sediment samples and scuba divers observations. 6 Sediment sample were taken randomly under FC Siulung by scuba divers and employing Van Veen graper. Two sediment cores (25cm x 5cm) were taken at the sea floor just beneath the trap cluster St2 (FC Siulung) and at REF2 (reference location), respectively. In the field laboratory, sub-samples were taken over the entire core length. After registration of sediment type, colour, stratification, structure and compactness the samples were dried. In the laboratory at Kiel University they were analysed for properties, composition and compounds.

5. Hydrodynamics

Surveys of tidal currents flanked the sampling of suspended matter. A gimbal-mounted current meter (Aanderaa SD-6000) attached at a rope and submerged near the trap cluster St1 registered over a period of eight days (Sep15-23, 2005) the tidal current velocity and direction in 8m water depth. The storage interval was 1min. Since the rope the was fixed to the catwalk the distance between current meter and sediment traps kept constant, while the distance of the device to the sea floor varied within the tidal cycle. The currents inside the tidal channel close to the reference station REF2 were estimated by applying a numerical flow model. It was developed by Windupranata (2005) and based on the DELDFT3D model family. A pressure gauge recorded the tidal oscillation of water level from Sep17 to Sep27, 2005. The storage interval was 1min. The positions of the current meter and gauges are indicated in Figure 7.

Figure 7: Propeller current meter and pressure gauge positions

6. Analysis of sediments

TOC

The analysis of total organic carbon (TOC) was performed by operating a STRÖHLEIN Coulomat 702. The dried samples were de-salted and homogenised. Sub-samples were taken and ground for 10 minutes in a pebble mill. 50mg of the ground matter was taken for analysis of total carbon carried out by ignition of the sub-sample in oxygen gas flow (2 minutes at 200°C, 8 minutes at 800°C) and coulometric determination of the CO_2 released. A similar amount of matter was taken for determination of the inorganic carbon compounds by measuring the CO_2 release during carbonate decay in phosphoric acid (10 minutes). TOC was determined by subtracting the inorganic carbon compound from the total carbon compound.

Porosity and density

The determination of the porosity of sediment samples taken by graper or scuba divers was not always successful because many samples were disturbed. The porosity and the bulk density was experimentally approximated by analysing the parameters under the condition of the loosest sediment layering and the densest sediment layering, so that always ranges and means were delivered.

Grain size distribution

Sub samples of matter were treated with a H_2O_2 solution to decompose sticking organic compounds and split agglomerations, de-salted and then dried. According to the differing transport and deposition behaviour of fine and coarser particles two different practices of analysis were applied:

<u>Lasergranulometer</u>, suited to grain sizes < 63µm (clay, fine-medium-course silt)
Principle: A laser beam passing through a fast rotating prism meets a suspended particle in a measuring cell. The particle's shadow meets a high resolving detection plane, which measures the grain size in a detection range between 0,5µm and 150µm.
<u>Sieving</u>, suited to grain sizes > 63 µm (fine-medium-coarse sand and cooarser)
Principle: A de-salted and dried sediment of grain sizes > 63µm is given into a tower of sieves arranged downwards to decreasing mesh widths. The tower is exposed to eccentric rotations. The grains pass sieves with coarser mesh size and are retained in the sieve showing mesh widths smaller than the grain's diameter.

Statistics

Cluster Analysis was applied as multivariate statistical instrument (BACKHAUS et al. 2006) to clarify (un)similarities of characteristics and compounds between suspended matter and sediments on the sea floor according to the Euclidian distance. The Variance Analysis (ANOVA) was employed to test the relationship between the considered sediment groups by analysing the relation of the internal variance to the variance in between. For Cluster Analysis and Variance Analysis the program *kyplot* (Yoshioka 2001) was employed.

7. Results

Deposition rates

Table 1 shows a review of the depth related deposition rates DDRd of suspended matter in g/m²/day at the locations St1, St2, St3 in FC Siulung during the measuring period Sep19-22, 2005. Sampled water depths: 4m, 6m and 8m.

Table 1: Depth related deposition rates at St1, St2, St3, FC Siulung

Sediment trap	Depth [m]	Suspended matter, mineral and organic compounds [g/m²d] (measured)	TOC [g/m²d] (measured)	Mineral compound [g/m²d] (calculated)
St1	4	393.6	7.9	385.7
	6	448.1	8.8	439.3
	8	344.7	6.9	337.8
St2	4	403.3	7.9	395.4
	6	380.8	7.2	373.6
	8	382.5	7.1	375.3
St3	4	289.0	5.4	283.6
	6	174.6	3.0	171.6
	8	347.0	5.2	341.8

Table 2 shows the DDRd of suspended matter in g/m² per 3 days (measured) and per day (calculated) at St2 in FC Siulung versus reference station REF2 during the measuring period Sep22-25, 2005. Sampled water depth: 4m, 6m, 8m and 10m.

Table 2: Depth related deposition rates at St2, FC Siulung and REF2, reference station

Sediment trap	Depth [m]	Suspended matter [g/m²3d] (measured)	Suspended matter [g/m²d] (calculated)	TOC [g/m²d] (calculated)	Mineral compound [g/m²d] (calculated)
St2, 3d	4	337.3	112.4	2.4	110.0
	6	661.4	220.5	3.8	216.7
	8	1038.4	346.1	6.4	339.7
	10	1089.5	363.2	7.5	355.6
REF2	4	439.8	146.6	1.8	144.8
	6	244.6	81.5	0.9	80.6
	8	827.8	275.9	3.9	272.0
	10	1393.5	464.5	6.8	457.7

Derived from Table 1 and Table 2 the DDRd for suspended matter and TOC averaged over depths and measuring periods are indicated in table 3.

Table 3: Averaged DDR_d for suspended matter and TOC

Sediment Trap	**Averaged DDR_d Mineral + organic compounds (measured) [g/m²/d]**	**Averaged TOC (measured) [g/m²/d]**	**Mineral compounds (calculated) [g/m²/d]**
St1, St2 (n=17)	413	8.0	405
St3(n=8)	282	5.5	276.5
St2 after 3 days (n=4)	261	5.1	255.9
REF3 after 3days (n=4)	242	3.2	238.8

During the measuring campaign the cultured fish was fed with trash fish so that the mineral compounds like carbonates or terrigenous particles were delivered from natural sources. According to the TOC analysis of sampled matter at REF2 considerable amounts of suspended carbon originates from external sources (natural sources included). In principle the numerical difference of the C load in suspended matter determined at FC Siulung and at REF2 could deliver the C load that the fish farm released to the environment. This was acceptable if the depositional environment at REF2 could actually represent the depositional environment at FC Siulung before the fish farm had been installed. This assumption could statistically not be confirmed.

Sediment characteristics

The sea floor sediments (0-5cm depth) beneath the fish farm are generally characterized by broad grain size spectra. While carbonate compounds (corals, shells, forams etc.) are of marine origin, silicate compounds are likely to be delivered from terrigenous sources. The mean of the sediments grain size ranges between 200 and 630µm (d50 at 490µm). Fragments of corals represent the coarser fractions. In general they are poorly sorted with fine sand, medium sand as well as clayey and silty compounds. Essential grain size parameters are listed in table 4.

Table 4: Grain size parameters of the sea floor sediments

Stations	**TOC**	**mean [µm]**	**d50 [µm]**	**< 63µm [g]**	**< 63µm [%]**	**63-200µm [%]**	**200-630µm [%]**	**630-2000µm [%]**	**> 2000µm [%]**
SD6000	0.32	899.04	1846.82	1.32	5.1	5.9	18.1	22.4	48.5
N Siul	0.36	323.97	306.66	2.28	8.6	24.5	47.5	13.9	5.5
Einfahrt	0.53	517.39	462.66	2.04	8.9	11.5	32.4	15.6	31.5
OstMSiul	0.13	631.23	580.56	1.89	7.5	6.8	29.0	21.8	34.9
core	0.69	372.40	436.90	3.76	15.4	9.5	32.0	24.5	18.4
Zentrum	0.15	301.00	280.00	1.79	5.4	40.3	26.9	21.3	6.0
SE	0.38	690.00	1104.00	4.3	10.2	6.6	19.4	21.8	41.9
Referenz	0.40	236.67	191.47	4.7	23.17	47.3	21.1	7.7	0.7

The clay-silt compounds < 0.063mm of the sea floor sediments under FC Siulung were found to range from 5 to 16 weight%. However, while the silt particles of sizes < 0.040mm were found to make 4-13weight% of the sea floor sediment, this size fraction represents more than 99,8% of suspended matter sampled in the (suspended sediment) traps at FC Siulung and REF2.

Moreover, sediment analysis indicate that sea floor sediments at REF2 essentially consist of ca. 70% fine sand with 25-30% silt compounds (d50 at 190µm). Coarser compounds were not observed. The deposits are weekly cohesive and show an average porosity of 58%. Sediments (0-5cm) and sediment cores (0-20cm) did not show any stratification. Sediment layers that might have indicated the deposition of suspended matter (as may be expected at sea floor sections exposed to farming emission) were observed neither at FC Siulung nor at REF2. Moreover, indicators of settling as stratification, level change, consolidation and grain sizes information were assessed as being to weak to deliver reliable signals for proving accumulation tendencies neither under FC Siulung nor at REF2.

Hydrodynamics

Figure 8 reflects the evolution of tidal curve and current velocity. The graphs are combined to the accumulation of suspended matter in the trap cluster St2 (black dots). The daily deposition rates [g/m²] are continuously summarized over the observation period.

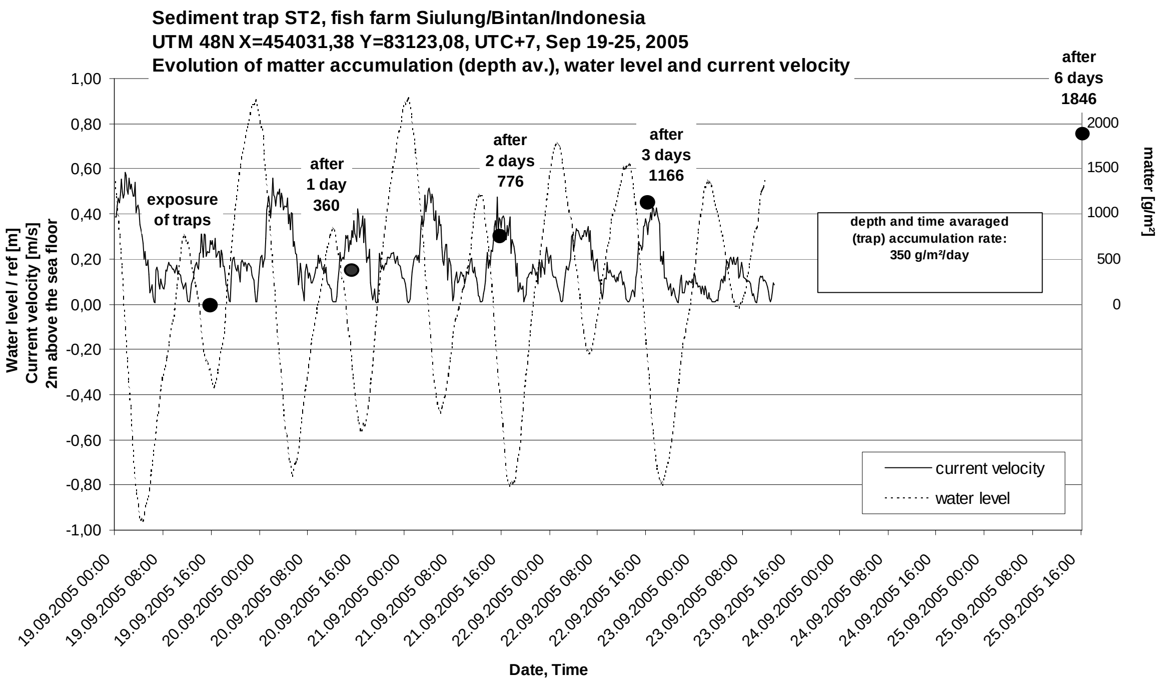


Figure 8: Current velocity, water level and accumulation of matter

During the observation period of the trap clusters ST1, ST2, ST3 the currents velocities under the fish farm Siulung increased to values between 40 and 60cm/s. The critical shear stress is the traction which is responsible for the initiation of the movement of a particular fraction of the sediment particles. It can also be expressed by the critical shear velocity at which the particles start to move.

The average critical shear velocity for the sandy sediments found below FC Siulung was determined to be 0.4m/s (0.3-0.6m/s). During the measuring period this critical velocity was exceeded several times per day for intervals ranging between a few minutes to several hours (Figure 9).

This indicates that bed transport occurs below the fish cluster Siulung. For organic material, having much smaller grain sizes, current velocities between 0.08 to 0.1m/s were found to be sufficient to keep most of the organic waste material in suspension (Peterson, 1999, Yokoyama et al., 2006, Cromey et al., 2002). Considering these values, over half of the measuring period (about 68% of the time) organidc matter would be prevented from settling to the sea floor due to too high current velocities.

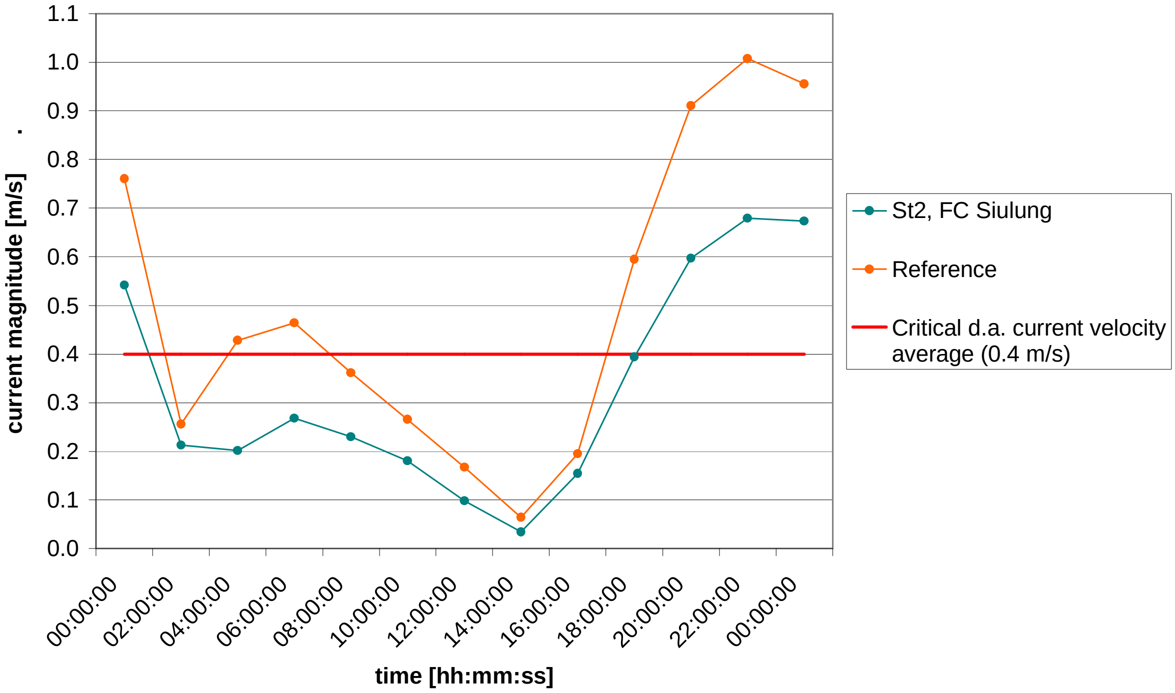


Figure 9: Current velocities at St2, FC Siulung (measured) and at REF2 (modelled). The dotted line indicates the critical current velocity (0.4m/s)

8. Discussion

Deposition rates

The deposition rates of suspended matter and TOC found under the fish farm Siulung are characterized by

- horizontal variations across the trap clusters
- vertical variations across the water depth
- temporal variations over the time of exposure

The depth related deposition rates measured at St1, St2, St3 were computed to check the vertical and horizontal homogeneity of suspended matter. Table 5 and table 6 present the results of the ANOVA referring to the tested features “suspended matter” and “TOC”.

Table 5: Deposition rates of suspended matter and results of ANOVA for testing the spatial homogeneity of suspended matter between the trap clusters St1, St2, St3

ANOVA	**Feature:** **Deposition rate of matter [g /m²/day]** **Matter sampled from sediment traps ST1, St2, St3 over 3 depth stages over 3 days (refer to 1m²)**								
sample time	19.09.2005 15:00			20.09 2005 15:00			21.09 2005 15:00		
depth stage	4m	6m	8m	4m	6m	8m	4m	6m	8m
trap St1	404,79	401,23	600,29	442,17	559,25	trap loss	333,89	383,73	400,87
trap St2	455,45	368,12	258,32	409,93	353,93	483,16	344,57	420,25	405,96
trap St3	219,31	194,84	568,00	349,46	154,31	145,56	298,19	trap loss	327,48
H0: The weights of matter in ST1, ST2, ST3 belong to the same weight population (alpha=0,05; beta<0,3)									
Factor	SS	Df	Ms	F(cal)	Signif	P(F<=F(cal))	F(0,05)		
A (Between Groups)	104981	2	52490,55	5,03312	* (P<=0.05)	0,01585	3,44336		
R(A) (Within Groups)	229439	22	10429,03						
AR (Total)	334420	24							
>>> H0 rejected, difference identified									

Table 6: Deposition rates of TOC and results of ANOVA for testing the spatial homogeneity of TOC between the trap clusters ST1, ST2, ST3

ANOVA	**Feature:** **TOC [weigt%]** **Matter sampled from sediment traps ST1, St2, St3 over 3 depth stages over 3 days**								
sample time	19.09.2005 15:00			20.09 2005 15:00			21.09 2005 15:00		
depth stage	4m	6m	8m	4m	6m	8m	4m	6m	8m
trap St1	2,04	1,92	1,82	1,98	2,03	trap loss	2,04	1,88	2,04
trap St2	1,88	1,89	1,94	1,84	1,88	1,75	2,25	1,9	1,95
trap St3	1,93	1,65	1,53	1,86	1,77	1,14	1,83	trap loss	1,6
H0: TOC in ST1, St2, ST3 belong to the same TOC population (alpha = 0,05; beta < 0,3)									
Factor	SS	Df	Ms	F(cal)	Signif	P(F<=F(cal))	F(0,05)		
A (Between Groups)	0,43410	2	0,21705	7,38867	** (P<=0.01)	0,00351	3,44336		
R(A) (Within Groups)	0,64628	22	0,02938						
AR (Total)	1,08038	24							
>>> H0 rejected, difference identified									

The horizontal and vertical depositions rates clearly show variations. The ANOVA results indicate that the variations for suspended matter and for TOC <u>between</u> the clusters St1, St2, St3 are significantly higher than <u>inside</u> the clusters so that the H0 ("homogeneity is given") is rejected ($n=25$, $\alpha=0.05$, $\beta<0.3$). Further analysis referring to the tested features "deposition rates of suspended matter and of TOC" confirm that:

a) The depth related deposition rates and TOC of suspended matter in trap cluster St3 that is located closest to the tidal channel differs from St2 and STt3.
b) No depth related difference of deposition rates and TOC between the sampling stages in 4m, 6m and 8m depth can be found.
c) No time related difference of deposition rates between the days the traps were sampled.
d) There is no difference between the trap cluster St2 (3 days) and the clusters St1 and St2, over 3 days according to high variations.
e) However, there is a significant difference of the deposition rates and TOC between St2 (3-days-exposure of trap) and the reference station REF2 (3-days-exposure of trap).

Sea floor sediments

Derived from the mean density of the sediment under the fish farm (2,45g/cm³, s= 0.22) und the average porosity (45,6%, s=6,0) the averaged weight of dry sediments of the sea floor between 0-1cm can be approximately calculated to 13.322g/m². This sediment embeds 8.7% (s=3.5) clay and silt. As 80.1% (s=8.1) of sediments grain size fraction <40µm consists of clay and silt, the weight is calculated to 1.159g/m². This amount of grain sizes < 40µm is less than 3-times the average daily deposition rate of fractions <40µm of 413g/cm² derived from the trap clusters under the fish farm Siulung. If this amount of suspended sediments actually settled in mid-term time scales, the accumulation of matter and the partition of the grain size fraction < 40µm on the sea floor should be expected to be higher by far. But this phenomenon was not observed.

The same calculation may lighten the sedimentological state close to the reference location REF2. Derived from a density of 2.46g/cm³ (s=0.27), an average porosity of 58.5% (s=6.4) of the sediments dry weight can be calculated as 11.316g/m² of which 30% is taken by the silt and clay compounds. The sediment fraction <40µm comprises 68.2% (s=4.2) of silt and clay so that a dry weight of 2.315g/m² is calculated. Compared to the deposition rate found in the trap cluster REF2 the amount of matter < 40µm in the sea floor sediment is 10 times higher than the amount of matter < 40µm found in the suspended matter.

Ratios of clay and silt compounds

Fine grained particles < 20µm found in suspended matter and as sea floor sediment compound are generally transported as suspended load. In order to decode the origin of the fine grained matter in the sediment, the ratios R of the contents of the clay + fine silt compounds (6.5µm) and the medium silt compounds (7-20µm) in the grain size fraction <20µm (set to 100%) were determined.

$$R\,[\ \ ] = \frac{\text{w\% clay [w\%] + fine silt [w\%] (* 6,5µm)}}{\text{medium silt [w\%]}}$$

The results related to suspended matter and sea floor sediment matter are listed in Table 7

Table 7: Ratios between sea floor sediments and suspended particulate matter

Location	**n**	**Sample**	**Depth**	$\mathbf{R_{mean}}$	$\mathbf{R_s}$
fish farm	5	Sediment	0-5cm	0.80	0.07
	13	Water	0-10m	0.87	0.07
reference	4	Sediment	0-24cm	0.28	0.01
	4	Water	0-10m	0.76	0.01

Employing ANOVA it was tested if R may decode systematic relationships and groups between suspended matter and sea floor sediment

a) at the fish farm Siulung and
b) close to the reference location.

Considering the fish farm ANOVA does not reject H0. The ratios of the considered fractions in sediment (R_{mean}=0.80) and in the suspension (R_{mean}=0.87) are statistically homogeneous. However, close to the reference location the ratios in the sediment (R_{mean}=0.28) and in the suspended matter (R_{mean} =0,76) vary tremendously. The cluster analysis (Fig xxx) arranges the tested objects so that specific groups are identified reflecting the similarities and distances related to the considered ratio.

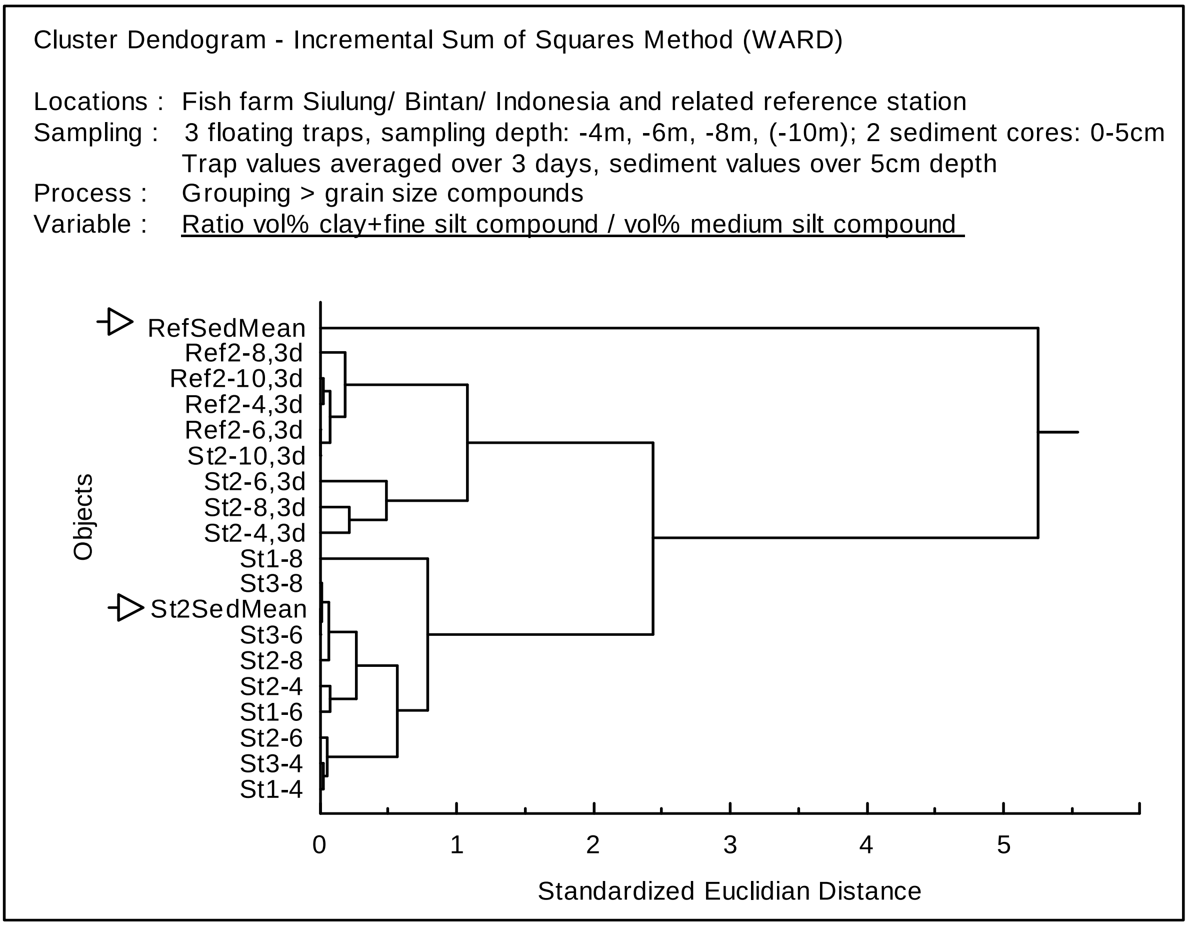


Figure 10: Results of the cluster analysis

9. Conclusion

As indicated in Figure 1 the level of critical shear stress under the fish farm is daily exceeded for several hours. This implies that

a) mineral-organic sediment particles mostly agglomerated to flocks, fragment of faeces and waste food are finer grained and/or of much lower specific density than the bottom sediments. They get in motion long time before the critical shear stress for the much coarser sediment is exceeded
b) long-term accumulation of suspended matter in the hydraulic environment close to the fish farm is unlikely considering the concentrations found

According to the tidal dynamics under the fish farm the deposition of suspended matter may be narrowed to periods of little water movement given close to high water and low water level. Re-suspension will take place with increasing current velocities. On the other hand, the sediment samples from the sea floor indicated that a deposition must have taken place nevertheless. Actually small scale deposition of fine grained sediment and matter exchange at the sediment-water interface may take place if suspended matter drifting close or settling to the sea floor is physically and/or biologically captured

a) in small caves, niches, holes or gaps in and between coarser matter on the sea floor, e.g. coral fragment, shells, worm tubes, garbage etc., where the fine grained matter may be sheltered against re-suspension
b) by activity of benthic fauna, e.g. bio-filtration, bio-deposition of fed matter, that is finally bioturbated into the coarser sediment.

The poor sorting of the sediment below the fish farm caused by mixtures of coarse and fine sediment compounds, thus leading to a broad grain size spectra, points out that the fine grained sediment compounds in particular are not very balanced to the hydrodynamic environment. The magnitudes of deposition rates measured in the trap clusters may not be uncritically transferred to the sea floor. The rates observed reflect more a potential of deposition in protected environments as is it artificially given in a sediment trap.

In the fish farm area the results of the statistical analysis point out that the fine grain particles in the sediment and in the suspension show close similarities in the distribution of their finest compounds. This supports the assumption that the suspended matter drifting over the sea floor may be considered as essential source for the finest compounds that are found in the bottom sediments, as well. Although only the ratios of mineral compounds has been analysed this source may include external suspended loads and particulate matter released from the fish farm. As discussed above sheltering effects, biodeposition and bioturbation likely supported the deposition of the small particles.

However, considering the ratios close to the reference location there are unconformities of the composition of the finest grain size fractions between suspended load (R_{mean} =0,76) and the sediment (R_{mean}=0.28). Whereas, at least, similarities to the grain size composition of the suspended matter at the fish farm are given, the ratios indicate that the content of medium silt in the sediment is much higher than in the suspended matter.

This discrepancy may have several causes that have to be weighted against the hydraulic, depositional and geological background. On the one hand this discrepancy between suspended matter and sediment could be a random event if the investigation period was to short for receiving more representative results valid for longer time scales. Maybe variations in the depositional system are responsible. On the other hand depositional events should have left their fingerprints in the fish farm area as well. Such signals could neither be observed nor be solved by the data and the statistical procedures - this does not mean that they actually do not exist. The question, how the fine grained sediments at the reference location settled and consolidated in the strong current regime still remains unanswered.

It is possible that the silt fine sands are old depositions related to event in the geological history since there are only weak links to the recent hydrodynamic environment, the depositional process and the suspended matter. It is less conceivable

- how this type of cohesive sediment in question may have deposited and consolidated under the recent tidal flow regime in the channel
- how the recent suspended matter may represent an essential source (as it was concluded for the sea floor under the fish farm)

A dating of the sediment core applying Pb^{210} and C^{14} would deliver more confidential results of the depositional process in the central tidal channel.

Considering the results the organic flux to the sea floor is an important criterion of danger for the sediment quality but in tidal environments it is not always the decisive one. The depositional and hydraulic conditions especially the potential of the tidal currents to prevent the depositions of organic waste or to remobilise already settled matter are important magnitudes that should compulsorily be considered.

A confidential relationship between suspended matter and the sediment’s composition is not always given if the hydraulic environment prevents suspended matter released to settle or if the general depositional environment turns-off towards erosive tendencies.

Remobilisation of organic waste that may have settled during high tide or low tide on the sea floor is taking place when current velocities temporarily exceed the critical shear velocity of the settled organic waste. The determination of deposition rates employing sediment traps in tidal environment is not always reliable if temporarily settled matter is re-suspended and moved-off by tidal currents. Sediment traps are not yet designed to allow remobilisation of matter.

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Sedimentological studies for investigation of fish farm impacts on the tidal coral reef platform at Pulau Siulung, Riau Archipelago, Indonesia

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Coastal Research & Management CRM

1. Introduction

Coastal cage fish farms, operational facilities and associated houses and cabins for workers and families are sources of effluents released into the marine environment. Considerations of impacts mostly focus the attention to the nutrient release and risks involved for the marine environment. A number of studies have stated that the intensive release of organic waste from fish farms may seriously impact the sea floor and deteriorate the sediment quality in den vicinity of cage fish farms (Krom & Neori 1989, Pereira et al. 2004, Porello et al. 2005, Seymour & Bergheim 1991, Brown et al. 1987, Rosenthal 1994).

Thus adequate tidal flushing and oxygen supply, spatial dispersion and transport combined to a rapid bio-decomposition of excrements and waste food is a vital prerequisite for sustainable farming to prevent accumulations to the sea floor and damage to the marine environment. In this context Wu (1995) indicates that more than 80% of P and C in food taken up are released in the marine environment as metabolic products (respiration, excretion) and waste food. Holby & Hall (1991) indicate that about 80% P offered in fish food was released from the fish farm observed, and estimated that ca. 60% of this quantity accumulated to the sea floor sediments. According to Hall et al. (1990) 75-78%C of the fish food of a trout fish farm in Sweden got lost to the marine environment; 18%C of the food settled as excretions to the sea floor and accumulated.

The flux of organics released to the sea floor may trigger adverse chemical processes in sediments. If the oxygen demand in sediments exceeds the diffusive supply the aerobic decomposition of organic matter turns to anaerobic that decisively deteriorates the environmental condition for benthic flora and fauna. According to the dispersion of matter in the falling and settling process the fish farm’s impact area on the sea floor is considered to be closely limited. Thus Gowen & Bradbury 1987, Hall et al. 1990, Angel et al. 1995, Schendel et al. 2004 observed a decrease of organic contamination with growing distance from fish farms. Wu (1995) reports the impact area around a fish farm to be limited to 1 km.

On the other hand Aguado-Gimenez & Garcià-Garcià (2004) found increasing concentrations of organic matter with increasing distance from the farm. They refer this phenomena to external organic sources.

Actually the marine and terrestrial primary production in particular in the coastal transition zone is a significant nutrient source for coastal environments. In order to achieve a better assessment of the relevance of emissions of a cage fish farm “Hiang Fisheries”, Pulau Siulung, Riau Archipelago, Indonesia in local and regional scales the need was identified to carry out investigations in the adjacent tidal flats. Emphasis was given to the spatial distribution and variability of sediments and embedded particulate organics with increasing distance from the fish farm. The investigations aimed at contributing to answer the following questions:

a) Are there indications of an extending influence of fish farm emissions on the sediment composition in regional scales?
b) Is there any evidence of contamination in the adjacent tidal flats?
c) Is the fish farm an outstand “hot spot” for organic contaminations of intertidal sediments?

The investigations were carried in Mai 2006 contributing to the objectives of the project “Development of a Decision Support System for the Sustainable Management of Coastal Living Resources“, 2004-2007, SPICE (Science for the Protection of Indonesian Coastal Ecosystems) which has been supported by the German BMBF, the Universities of Bogor (Java) and the University of Riau (Sumatra)

2. Investigation area

The company *Hiang fisheries* operates a cage finfish farm located between Pulau Siulung and Pulau Serai south of the Kijang on Bintan island, Riau Archipelago, Indonesia. The farm consists of more than 300 fish cages combined in two floating cage clusters close to Siulung and Serai, respectively. Yearly production rates of fish achieve 80t per year (van der Wulp, 2006). The farm is associated to a smaller fisherman village. Houses and cabins are constructed on stilts in the tidal flats close to the coastline. In inhabited coastal sections the mangroves have been felled to facilitate the inhabitants access to the sea. A shallow platform of destructed corals periodically flooded in the tidal cycle and extending 100-300m from the coastline to the sea surrounds the island Siulung. In between the corals smaller and broader patches of sediment are enclosed. At the seaward rim of the platform the tidal flats steeply slope towards a broad tidal channel reaching a water depth of 14m and separating Pulau Siulung and Pulau Serai. The mean tidal range is 2m. Farm facilities and cages are installed just over the slope representing a transition zone from the inter-tidal platform to the sub-tidal sea floor. It was found that tidal currents in the transition zone reaching 60cm/s close to the bottom (during the measuring period) widely disperse and move-off organic waste released from the fish farm (Niederndorfer & Runte 2007). The currents temporarily exceed the critical shear velocity of matter settled on the sea floor beneath the fish farm at high tide and low tide and resuspension takes place. So significant organic accumulations on the sea floor beneath the fish farm were neither observed by scuba divers nor identified in graper samples. Nevertheless there was no reason for excluding that unknown quantities of matter released could be transported by the tidal flow and deposited in the tidal platform. First observations in the area confirmed the occurrence of some finer grained deposits over coarser sediment, which became subject of the presented investigation.

3. Methods

Resulting from observations in 2005 a sediment sampling was carried out in May 2006 along a 10km transect crossing the tidal platform of Siulung towards northwest and northeast. Measuring stations were randomly defined in distances of 300-1000m and GPS positions were taken (Fig. 1). At each station 3-5 sediment samples (0-1cm depth) were randomly taken inside of a radius of 100m. Coastal distance, depositional environment, stratification, oxygen supply, colour and consistency of sediment were registered.

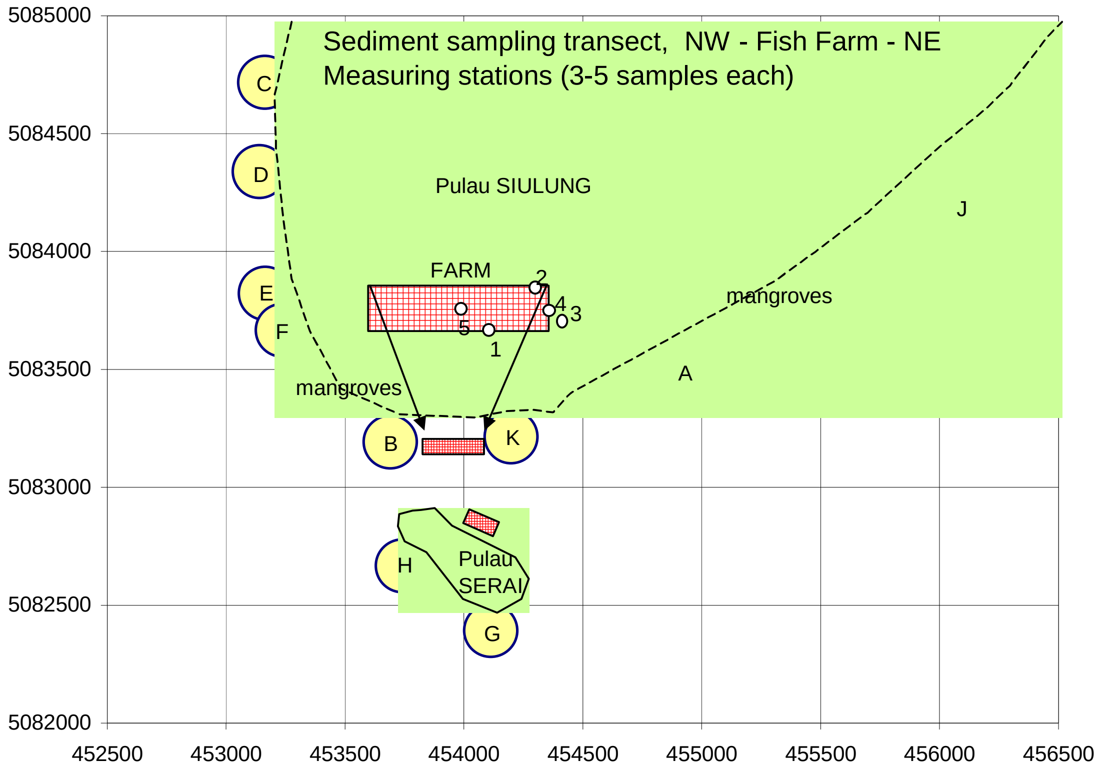

Fig.1 Positions of the measuring stations for sediment sampling, transect Siulung.

Another 5 sediment samples were taken on the sea floor beneath the fish farm by employing Van Veen graper. The sampled sediment was enclosed in bags (polyethylene) and later spread and dried in the sun (T at 45°). After drying the sediment was enclosed and air-transported to Kiel, Germany. In the laboratory of the Research and Technology Centre Westcoast in Büsum the sediment samples were allocated from the bags to small bowls, de-salted, dried and weighted.

For determination of the grain size distribution the sediments were split by sieving into the grain size classes <38µm, 38µm-63µm, 63µm-212µm, 212µm–630µm, 630µm–2000µm and >2000µm. According to the source the particulate organic matter in sediments often varies in size. Organic waste released from the fish farm, particularly excrements, was predominantly expected in the finer grain size fraction of the sediment so far it was exposed to farm emissions. In coarser sediment fractions other kinds and sizes of particulate organics, e.g. wooden detritus, leaves, (macro) algae, contribute to the total organic content in the sediment. To investigate the role of "grain size effects" of organic matter that could mask or even exaggerate the organic waste released from the fish farm the analysis of organic matter was extended to fractions < 38µµ, 38-63µm and 63-212µm of the sediment's grain size distribution. The fractions were split in a careful sieving procedure to diminish rubbing effects. The samples were weighted and tempered at 550°C and the loss of ignition of organic matter (LOI) was determined. For statistical computation cluster analysis were employed.

4. Results

4.1 Characteristics of investigation area

Fig. 2 presents an overview of the destructed coral reef platform. It is bordered by mangrove forests at the landside and by coral reef rims at the seaside. A brownish coating of clayey and silty matter often covers coral relics and attached green algae.

Fig. 2 Destructed coral reef platform, view to south at measuring station D

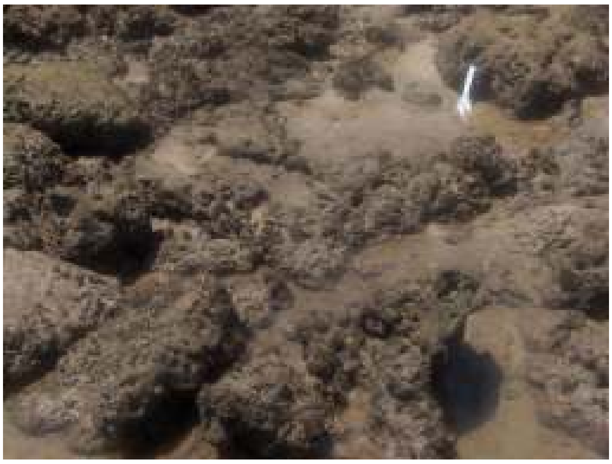

Fig. 3 Sediment sampling point D2

Patches of sediments composed of smaller coral fragments, broken shells, carbonate sand and silty-clayey compounds are enclosed in gaps and caves between the corals. Thin red-brownish covers of diatoms are observed. Under the surface black coloured sediments and a typical smell often indicate anaerobic degradation of organics. Fig. 2 shows the sampling point no. 2 at the measuring station D (see Fig. 1).

4.2 Classification according to grain size distribution

Tab. 1 lists the results of grain size analysis of the sediment sampled. The capitals refer to the respective measuring stations as indicated in Fig. 1. The numbers denote sub-samples taken at each measuring station.

Tab.1 Grains size fractions of sediments [µm], transect Siulung, 2006

Sample	F<63	F63-212	F212-630	F630-2000	F>2000	Sample	F<63	F63-212	F212-630	F630-2000	F>2000
A1	9,3	22,0	52,5	14,5	1,7	B1	24,9	36,5	36,6	1,4	0,7
A2	10,8	37,8	30,3	17,9	3,2	B2	24,1	31,8	33,7	8,2	2,3
A3	9,4	21,1	40,5	25,4	3,6	B3	8,2	76,6	14,5	0,5	0,1
A4	9,6	22,0	45,2	19,7	3,4	B4	21,7	39,9	35,4	2,0	1,0
A5	6,5	30,0	47,2	13,2	3,0	B5	13,8	66,4	17,1	1,8	0,9
J1	54,0	26,1	17,1	2,6	0,2	F1	4,5	18,0	26,8	26,5	24,2
J2	93,6	5,6	0,5	0,2	0,1	F2	6,3	47,7	28,7	8,0	9,3
J3	82,8	13,9	2,7	0,5	0,0	F3	6,9	47,8	30,7	7,8	6,8
H1	8,1	6,9	59,2	18,0	7,9	E1	3,2	34,3	19,0	27,8	15,6
H2	4,9	27,1	44,7	13,6	9,8	E2	7,7	46,0	22,3	17,7	6,3
H3	3,9	20,5	62,2	9,9	3,4	D1	6,0	70,2	21,4	2,2	0,2
G1	31,7	40,4	7,4	16,1	4,3	D2	5,2	66,9	26,8	0,8	0,3
G2	7,2	43,5	32,6	13,0	3,8	D3	4,9	67,7	23,4	3,5	0,4
G3	21,9	39,1	13,3	16,7	8,9	C1	8,8	31,6	48,4	10,2	1,0
FARM1	5,1	5,9	18,1	22,4	48,5	C2	5,0	24,6	52,7	16,7	1,0
FARM2	8,6	24,5	47,5	13,9	5,5	C3	19,5	32,0	23,7	18,2	6,5
FARM3	8,9	11,5	32,4	15,6	31,5	C4	14,7	20,8	30,5	28,5	5,6
FARM4	7,5	6,8	29,0	21,8	34,9	K1	4,4	49,4	29,6	11,4	5,3
FARM5	15,4	9,5	32,0	24,5	18,4	K2	4,3	25,9	67,3	1,8	0,8

Fig. 4 shows the relative significance of the sediment's grain size classes at each measuring station in cumulative histograms. The order of the stations refers to the distance from the fish farm Siulung.

Grains size distributions and standard deviations reflect a considerable variability in local and regional scales. Generally the sediments are composed of medium sand and fine sand with smaller contributions of finer and coarser compounds. On first view the histograms do not show tendencies that would indicate a trend or evolution of the sediment distribution referring to fish farm emission.

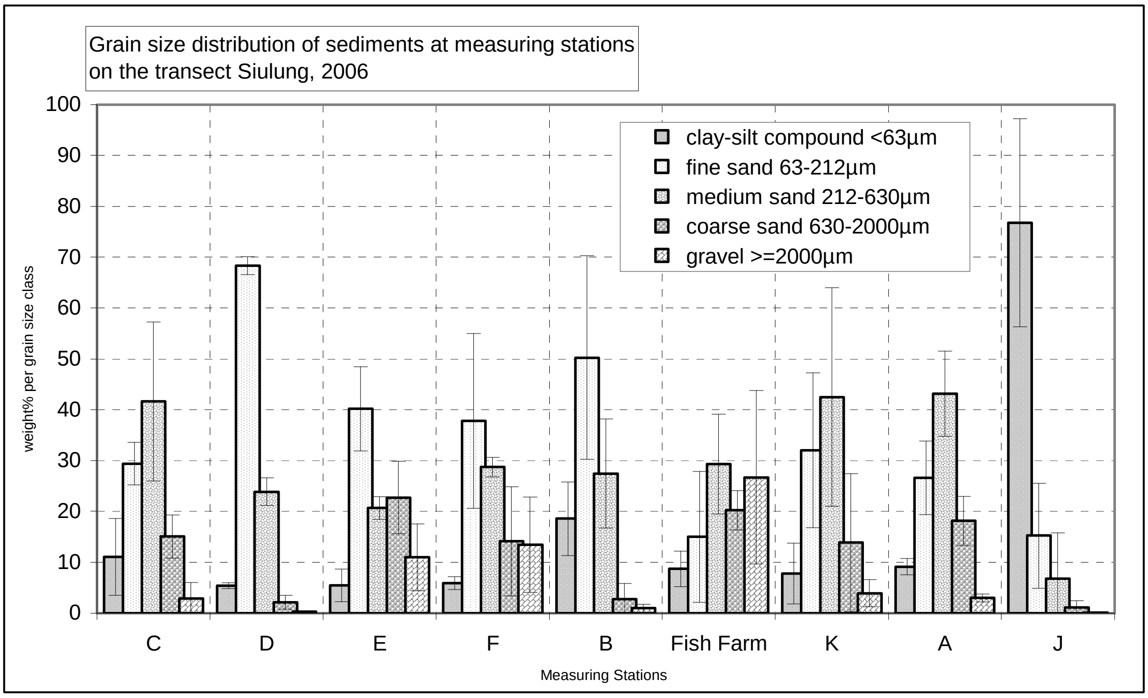

Fig. 4 Relative weightings of main grain size classes based on 3-5 sediment samples taken at each measuring station. The measuring stations are ordered according to their distance to the fish farm.

Fig. 5 shows the dendogram of a cluster analysis grouping the sediment samples according to similarities inside the grain size distribution, that is, the classifications describe the mutual numerical distance of the single sediment samples to each other in terms of the contents of clay and silt, find sand, medium sand, coarse sand and gravel. The capitals symbol the measuring station.

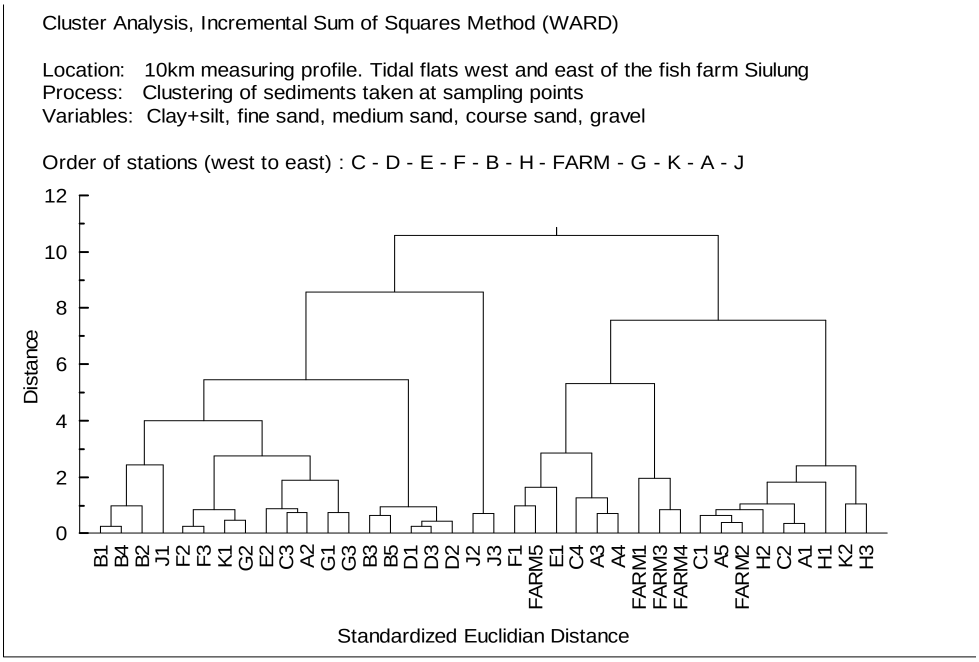

Fig. 5 Grouping of sediments according to similarities referring to the test variables.

The results indicate that sediments at the measuring stations show high variation in the grain size distribution in local and regional scales. The clustering process does not deliver similarities of sediments referring to varying distances of the fish farm, that is, no relationship is detected along the transect indicating influences of the fish farm referring to the sediment's grain size distribution.

4.3 Classification according to organic matter (OM)

Tab. 2 lists the results of measurements of OM contents [%] (loss of ignition) in grain size fractions of the sediment [µm].

Tab. 2 Contents of organic matter [%] in total sediment selected grain size fractions [µm].

Sample	F<38	F38-63	F<63	F63-212	Total Sed.	Sample	F<38	F38-63	F<63	F63-212	Total Sed.
A1	10,2	8,9	19,1	2,4	4,9	B1	10,4	9,8	20,2	2,7	10,9
A2	8,2	7,7	15,9	2,3	5,2	B2	13,1	14,4	27,5	6,8	2,3
A3	9,9	9,1	19,0	2,8	3,6	B3	11,3	8,9	20,2	6,5	4,0
A4	8,7	8,6	17,3	2,8	4,9	B4	9,1	7,3	16,4	2,7	4,4
A5	8,6	7,9	16,5	2,2	4,4	B5	11,3	10,4	21,7	2,0	5,1
J1	11,4	10,6	22,0	3,1	8,6	F1	4,5	18,0	26,8	26,5	24,2
J2	11,7	11,2	22,9	4,1	11,6	F2	6,3	47,7	28,7	8,0	9,3
J3	10,9	10,6	21,5	3,9	10,8	F3	6,9	47,8	30,7	7,8	6,8
H1	17,1	20,5	37,6	9,2	3,7	E1	13,2	8,4	21,6	2,6	3,1
H2	13,1	11,9	25,0	1,9	2,8	E2	14,1	12,7	26,8	2,6	4,4
H3	14,0	10,1	37,5	1,9	3,7	E3	14,7	13,1	27,8	3,1	4,4
G1	11,3	10,0	21,3	3,3	3,4	D1	17,1	11,6	28,7	3,3	5,0
G2	10,9	8,3	19,2	2,0	7,0	D2	8,0	7,2	15,2	3,8	4,3
G3	11,8	9,8	21,6	3,1	6,5	D3	13,3	7,4	20,7	3,4	3,9
FARM1	-	-	26,8	-	9,1	C1	16,8	10,7	27,5	2,6	6,0
FARM2	-	-	25,2	-	7,0	C2	15,9	10,1	26,0	2,4	3,0
FARM3	-	-	22,2	-	6,2	C3	12,4	8,9	21,3	5,2	2,0
FARM4	-	-	29,0	-	10,0	K1	8,6	7,4	16,0	1,4	0,8
FARM5	-	-	27,4	-	6,1	K2	7,4	3,7	11,1	0,7	1,7

Fig. 6 shows the regional evolution of OM in sediments at the measuring stations with increasing distance from the fish farm. The graphs indicate the content of OM both in the total sediment sample as well as in the sediments grain size fraction < 63µm, respectively. Each measuring station on the transect represents 3-5 local sub-samples.

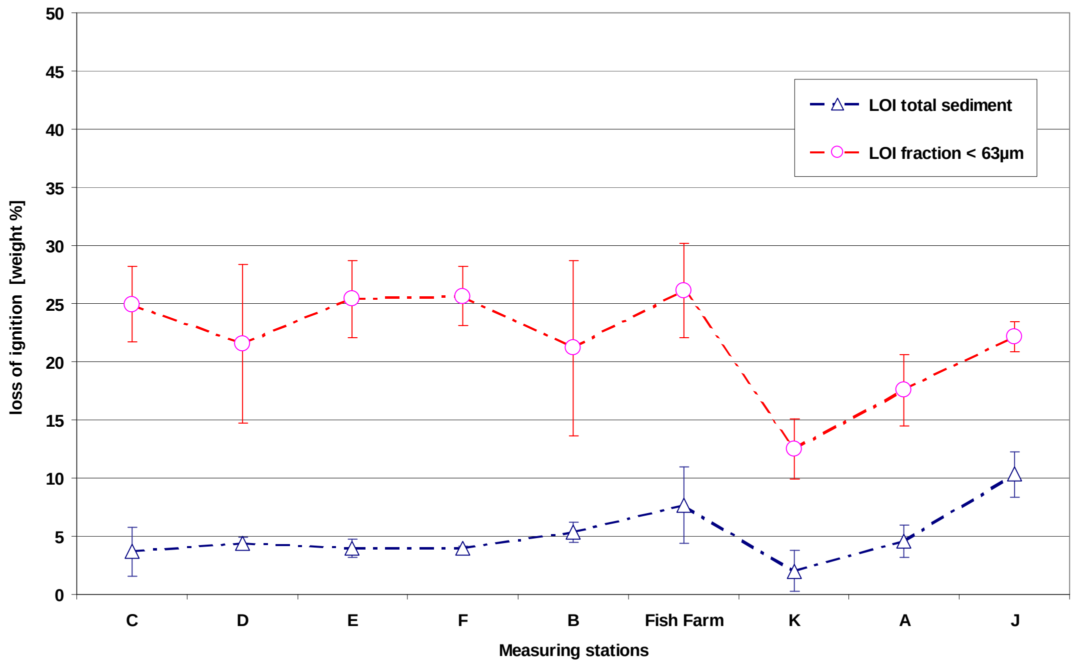

Fig. 6 Regional evolution of organic matter in sediments along the transect Siulung.

Compared to total sediment the content of OM in grain sizes <63µm is about 2-6 times enhanced along the transect. Beneath the fish farm the sediment's clay and silt compounds contain ca. 26% OM. Towards the north-western flats OM varies between 21% and 26% so that it does not significantly differ from the OM levels in fish farm sediments. Toward the east OM decrease significantly to a mean content between 13% and 22%.

Considering the total sediment OM shows a slight enhancement at the fish farm and regionally a slow decrease towards the northwestern tidal flats. Most values are still in the range of the standard deviation of OM close to the farm. In the northeastern tidal flats the development is less clear, as the values drop and then increase again. Here, as well, OM content in sediments at distant measuring points on the transect is still in the range of OM concentration in sediments close to the farm.

The sediments grain size fraction <63µm represent the grain size interval where dispersed organic particles released from the fish farm were expected to accumulate if there was an influence of the fish farm. The cluster analysis aimed to test if the grouping procedure identified relationships between the tested measuring stations that was founded on similar OM contents in the grain size classes <38µm (Variable 1), 38-63µm (Variable 2) and 63-212µm (variable 3) that moreover, refer to the distance to the fish farm.

The resulting dendogram in Fig. 7 shows the grouping of sediments according to the standardized Euclidian distance in between the tested sediment. The illustration indicates that the internal variations OM in the sediments at each measuring station (in terms of the of the variables tested) can be much higher than the external variation of OM in the sediment between the respective measuring stations so that no regional weightings can be identified.

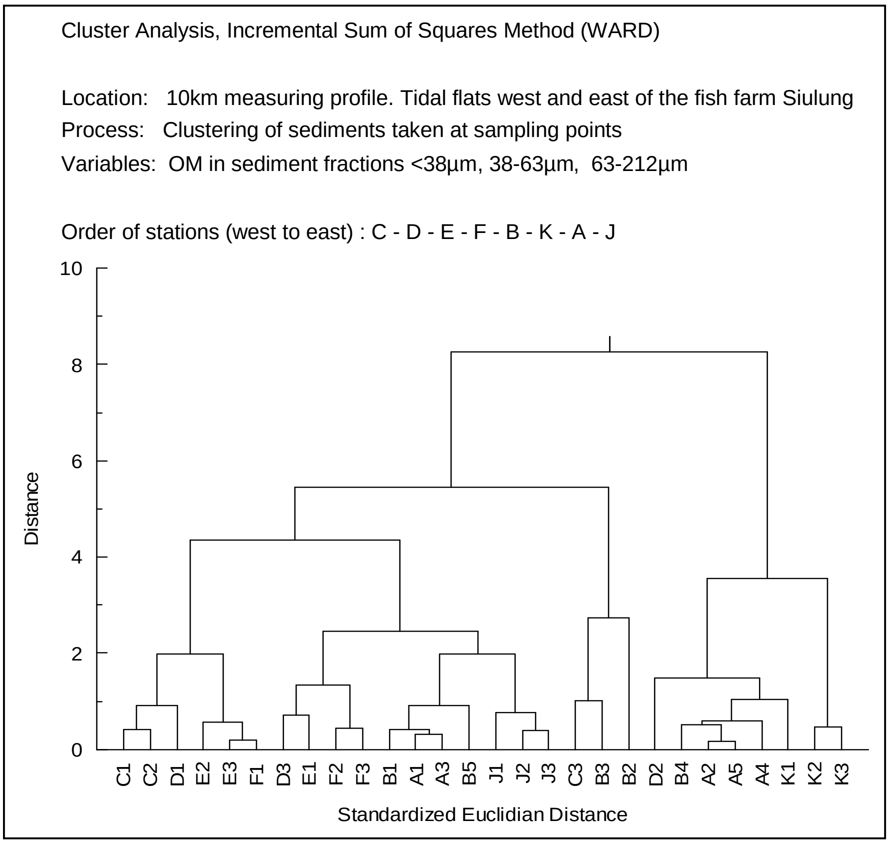

Fig. 7 Grouping of sediments according to similarities of OM referring to the tested variables: grain size fractions <38µm, 38-63µm and 63-212µm of sediments.

5. Discussion and Conclusions

The investigation carried out aimed to identify indications of extending influences of fish farm emissions at Siulung on the sediment composition of the adjacent tidal flats in local and regional scales. Moreover, it should be tested if contamination of the adjacent tidal flats in terms of enhanced organic matter contents referring to impacts of the fish farm may be observed.

On the base of the sedimentological and computational methods applied the results delivered no indications that would confirm a regionally extending influence of fish farm emissions towards the adjacent and distant tidal flat areas in terms of sediment distribution, sediment composition and particulate organic compounds.

High variations were found referring to the sediment's composition in local and regional scales indicating a inhomogeneous depositional environment. The most essential process delivering sand, gravel and coarser silt is the destruction of the coral platform. The dead corals are exposed to long-term destruction by currents and waves. To a smaller extent shallow section of the sea floor may represent another sediment source when orbital motion of waves and turbulences of breaking waves close to the reef rims under storm conditions initiate resuspension from the sea floor and transport even to higher coastal areas.

The finer compounds are derived from settlings of suspended matter during the daily tidal cycle. Referring to observations after rainfalls island effluents with heavy loads of terrestrial suspended matter ruffles the coastal water and deposit mainly in coastal sections where the mangrove belts have been destructed. On the other hand fishermen and workers of the fish farm Siulung consider companies mining bauxite ore on the neighbouring islands to be most responsible for the temporary increase of cloudiness, that is suspended loads, of the sea water. Consistency, colour and the spatial distributions of the coatings on the destructed coral point out that an influence of mining on the suspended load in the water was rather likely than to exclude.

Organic matter differs from conservative (mineral based) sediment compounds in terms of biodegradation, sources and accumulation processes. Organic matter released from the fish farm represents an attractive nutrients source for numerous marine organisms. Oxygen supply and sufficient dispersion proposed the matter is bio-decomposed to basic nutrient compounds, which are rapidly absorbed by the oligotrophic marine environment.

The hydraulic conditions close to the fish farm Siulung widely prevent a long-term deposition of organics released. Matter that has settled to the sea floor at time periods of low water motion at high tide and low tide are re-suspended by tidal currents when they exceed the critical shear velocity of the deposits. According to the hydraulic environment the fish farm area is exposed to the tidal dispersion of matter released is obviously so effective that the deposition of the matter in the adjacent tidal flats seems to be negligible low.

In more distant coastal section of Siulung far away from the fish farm other sources of organic matter in sediments have to be taken into account. In this context terrestrial effluents and detritus of the coastal mangroves may play an important role for the supply of the tidal flats with organic matter. Boto et al. (1991), Atmadja & Soeroyo (1994) found that mangrove forest export significant quantities of particulate organic matter to the adjacent coastal waters mainly in the form of mangrove plant litter. They indicate for coastal mangrove associations in West Java (Ujung Kulon) a net primary production of 17,3 kg carbon $ha^{-1}day^{-1}$; other species achieve 40-45 kg carbon $ha^{-1}day^{-1}$. According to the existing coastal mangrove forests belt in Siulung bordering the coral platform a tremendous influence of organic matter leaking out of the mangroves on the supply of sediment hase to be taken into consideration.

Moreover the primary production of diatoms and green algae on the corals and sediments is another significant source for organics in the sediments found. The natural supply in the tidal flats with organics obviously takes place in a magnitude that the amount of organic matter found in the tidal flats sediments is comparable to the amount of organic matter in sediments found close to the fish farm Siulung if the observed variability in terms of standard deviation is implied.

If statistically the 95% confidential interval of the mean OM contents in sediments (Gauss distribution proposed) is applied for assessment the relationship to sediments beneath the fish farm the contents are not enhanced: The natural variation of particulate organics in sediments covers or even mask a possible fish farm influence in local and regional scales.

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Sediments carrying capacity of organic pollution and cumulative effects by fish farming in a tidally influenced region in Riau region, Indonesia

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Abstract

The deposition of organic material, rates of organic matter breakdown and benthos community in the vicinity of two fish farms in a tidally influenced region of the Riau archipelago, Indonesia, have been studies. In general, the area is well suited for fish farming: The supply of oxygen caused by strong currents keep the water quality for the caged fish high, the bottom topography allows access of large boats as well as the attachment of the fishfarm to the ground, tidal currents remove practically all particulates from the seafloor thus preventing anoxic sediment conditions and environmental deterioration. Organic matter decay rates account for the breakdown of 0.5 to 2 g carbon per squaremeter and day, relating to the rate of deposition of organic material. Organic matter decay rates are a measure for sediment carrying capacity of organic pollution and are a useful tool for defining limits for single and multiple input sources.

1. Introduction

In the past 30 years, marine fish farming has become a major industry in many coastal areas of the world. Considerable ecological experience has been made, and it was not always a very pleasant one:

In the early days of marine fish-cage culture in the 70s, sheltered coastal areas – such as Norwegian or Scottish Fjords - were preferred as farming sites. The undesired side-effect of this choice was discovered soon afterwards: protected, sheltered areas tend to have limited water exchange; the excess feed caused eutrophication effects, in the water column as well as on the sea bottom.

In subsequent years efforts were made to minimize these undesired effects: Models helped to clarify the whereabouts of dispersed particular material (excess feeds, faeces) and diluted compounds (nutrients, Angel et al. 1995), current studies and improved feeds also helped to decrease the undesired effects.

The following table gives an overview of all potential ecological damages which can occur due to the presence of a net-cage fish farm.

Table 1: Observed consequences of fish farming for the environment

Problem	**Consequence**	**Subsequent consequence**
Food input	Increased load of particulate organic material	Organic enrichment on sea floor, Decrease of oxygen,
Food input		
High fish density in cages	Decreased oxygen content in water	
High fish density in cages	High metabolism	High ammonia loading of sea water
Net cages	Decreased current velocity	Decreased oxygen content in water
Fish farm construction	Mechanical damage to environment	
Use of antibiotics	Distribution of antibiotics in environment	
Genetically altered fish	Genetic mixing with wild population	
Fish diseases	Distribution of diseases in the environment	

As nothing in nature is ever constant, natural ecosystems have to be able to react flexibly to changing circumstances; however, this flexibility has its limits, and major negative ecological effects of anthropogenic disturbances are always the result of an imbalance between the magnitude of disturbance and the (limited) potential of the natural system to cope with the disturbance. Next to quantifying the disturbance – in this case mainly represented by the input of organic material through fish feed and faeces (Róisín-Niederndorfer 2006, Van der Wulp 2006) – the documentation of the *status quo* of the sediments a well as an assessment of the carrying capacity of the natural system will be the main tasks of this study. The paper will show that basic geochemical data are able to provide tools for estimation of sediment carrying capacity including cumulative effects as well as mitigation strategies for coastal aquaculture.

2. Study area

The study area in the Riau archipelago, Indonesia, has been described in detail elsewhere (Ladwig & Hesse in prep.). A settlement on Pulau Siuliung providing housing for approx. 30 families is prevailingly sustained by two fish farms at the island of Siuliung, south of Bintan

Island in the Indonesian Riau area. The area is subject of a very strong tidal regime, which generates currents up to 0.6 m sec^{-1} several times per day (Krost & Runte in prep.).

Bathymetry

The bathymetry in the study area is characterised by a channel system and coastal flats, stabilized by coral reefs. The flats have a water depth between 1 and 3 meters. Most of the settlements and also the fish farms are constructed in these shallow areas. The flats stretch about 50 to 300 meters from the coast into the sea and end in an extremely sharp slope descending from 3 meters to 11 - 13 meters water depth. Maximum water depth found in the study area was 16 m.

Sediments

A variety of sediment patterns was found; a prominent sedimentological feature was a thick grey layer of pure clay, which was found in most of the stations usually a few centimeter below the sediment surface (Runte in prep.).

Fish farms

Two major fish farms are operating in the study area, next to several smaller units which belong to various owners. The size, operation procedures and other farm details are summarised in Van der Wulp 2006. Both large operation were studied. For convenience, we refer to the Fish Farm close to Serai Island as “FF Serai”, the other on the southern side of the channel and close to our expedition base as “FF Lab”.

Materials and methods

Sampling and analysis techniques have been described in Hoppe & Krost in prep., Krost in prep., Krost & Runte, Van der Wulp 2006, Róisín Niederndorfer 2006, Runte & Krost in prep.

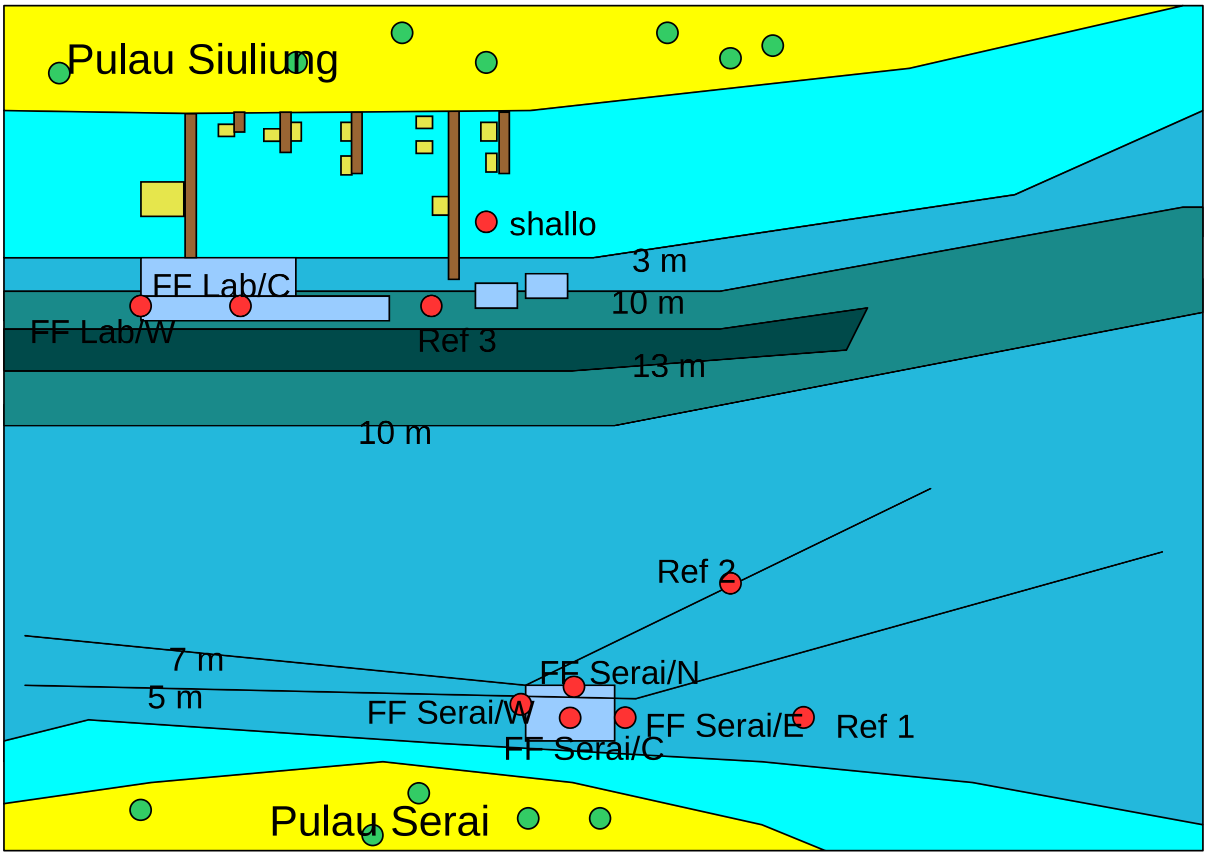

Fig. 1: Schematic visualisation of fish farms and sampling positions

3. Results

Organic pollution

No clear interdependence between the organic pollution of surficial sediments and fish farms could be found. In fact, lowest as well as highest concentrations were found directly underneath the fish farm, while reference stations in 100 resp. 1000 m distance showed intermediate values of organic content (fig. 2) the variance of the content of organic carbon in the study area exceeded the differences between sites underneath the fish farms and at reference stations.

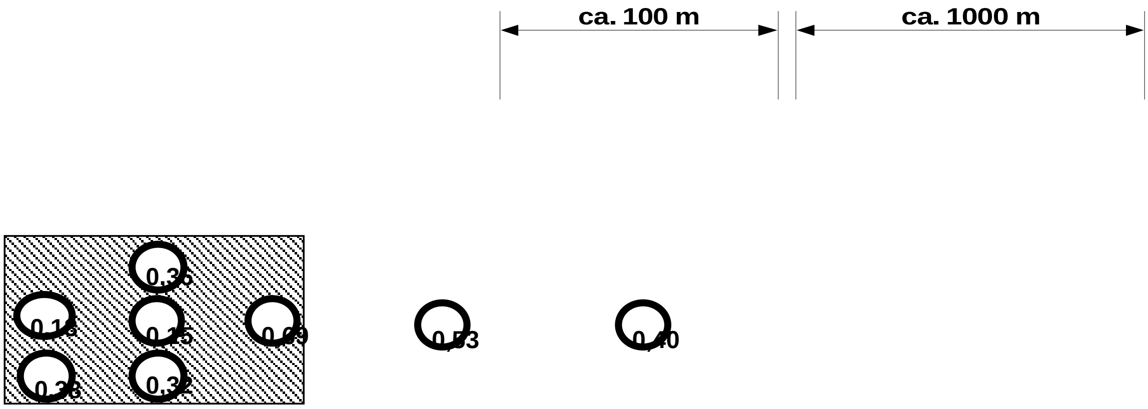

Fig. 2: Organic carbon in the study area at fish farm Siuliung. The dashed box indicates the position of the fish cages, the numbers in circles represent the percentage of organic carbon in the uppermost sediment layer. (data: courtecy of Dr. Runte, Kiel).

Benthic degradation rates

There are various ways of degradation of organic material in sediments, according to the site-specific conditions. The most prominent factor is the availability of oxygen which largely controls the speed of decay (Findlay & Watling 1997). The following table gives an overview over important metabolic processes and benthic assemblages, following Holmer et al. 2005).

Table. 2: Scheme of dominant metabolic processes and benthic conditions according to the oxygen suppl, following Holmer et. al. 2005.

<table>
<tr><td></td><td colspan="6">Benthic Oxygen Zonation</td></tr>
<tr><td></td><td>Oxic A (III)</td><td colspan="2">Oxic B (II)</td><td colspan="2">Hypoxic (I)</td><td>Anoxic (0)</td></tr>
<tr><td>Eh (mV)</td><td>> + 100</td><td colspan="2">+ 100 to 0</td><td colspan="2">0 to -100</td><td>< - 100</td></tr>
<tr><td>Total Sulfides (uM)</td><td>< 300</td><td colspan="2">300 to 1300</td><td colspan="2">1300 to 6000</td><td>> 6000</td></tr>
<tr><td rowspan="2">Dominant Metabolic Process</td><td colspan="2">Aerobic Metabolism</td><td colspan="2">Sulfate Reduction</td><td colspan="2">Anaerobic Chemosynthesis</td></tr>
<tr><td colspan="2">O_2 and CO_2
Respiration / Photosynthesis</td><td colspan="2">SO_4^{2-} reduced to H_2S and S^{2-}</td><td colspan="2">CO_2 reduced to carbohydrates by oxidation of H_2, H_2S, Fe^{2+}, NO_2^-</td></tr>
<tr><td rowspan="2">Dominant Benthic Fauna/Flora</td><td colspan="2" rowspan="2">Megafauna (> 5 cm)
Macrofauna (> 0,5 mm)
Meiofauna (< 0.5 mm)
Aerobic algae/bacteria</td><td>Meiofauna
Nematodes</td><td colspan="2">Protozoa
Ciliates</td><td rowspan="2">Anaerobic bacteria</td></tr>
<tr><td colspan="3">Facultative anaerobic bacteria</td></tr>
</table>

In order to determine the rates of benthic metabolism, the following approaches were used (for details see Krost in prep.):

1. Lab incubations: Sediment cores including overlaying water were sampled and carefully transported into the lab and cultivated in *in-situ* temperatures. The change of oxygen concentration in the overlying water was measured in a time series. This approach also prevents fish dwelling activity completely, and bioturbation of invertebrates to a large extent.
2. Porewater profiles: This approach is convenient under certain conditions, as it does not require sophisticated underwater work; it requires information on various sediment parameters and calculations for diffusive fluxes; this approach systematically ignores the role of bioturbation and water currents, and is therefore an underestimate of the real fluxes.

A reasonable match between the various methods and approaches was found, as summarised in table 3

Table 3: A summary of organic matter breakdown rates, calculated from different methodoligical approaches

Date of sampling	**Location**	**Water depth**	**method**	**C_{org} decay ($g\ C * m^{-2} * d^{-1}$)**
06.05.2006	FF Serai / E	5.8	Electrode (SOD)	1.39
07.05.2006	FF Serai / C	7.5	Electrode (SOD)	1.26
10.05.2006	Ref. 2	7.0	Electrode (SOD)	0.47
11.05.2006	FF Lab / W	12.0	Winkler titration (SOD)	0.39
11.05.2006	FF Lab / W	12.0	Winkler titration (SOD)	0.26
12.05.06	FF Serai / N	4.5	Winkler titration (SOD)	0.87
12.05.2006	FF Serai / N	4.5	Winkler titration (SOD)	0.49
12.05.2006	FF Serai / N	4.5	Winkler titration (SOD)	0.77
13.05.2006	Ref. 2	7.0	Winkler titration (SOD)	0.26
13.05.2006	Ref. 2	7.0	Winkler titration (SOD)	0.34
13.05.2006	Ref. 2	7.0	Winkler titration (SOD)	0.27
19.09.2005	Shallow water	2.0	Porewater (ammonia flux)	2.38
20.09.2005	Ref. 2	7.0	Porewater (ammonia flux)	1.35
21.09.2005	Ref. 3	10.5	Porewater (ammonia flux)	0.43
23.09.2005	FF Serai / C	7.5	Porewater (ammonia flux)	0.97
25.09.2005	FF Serai / E	5.8	Porewater (ammonia flux)	0.26
25.09.2005	FF Lab / W	12.0	Porewater (ammonia flux)	1.73

Benthos community

Neither the number of species, nor the abundance of individuals per unit area nor the diversity of the benthic community can be assigned to the distance respectively proximity to the fish farms.

In effect, the variation between benthos samples under or close to the fish farms and at reference stations did not exceed the variation that was found between different reference sites. We therefore conclude, that despite the high input of organic material (Róisín Niederndorfer 2006), and as opposed to the majority of reported situations underneath fish farms, no adverse effects on the benthic community could be detected, which could be directly assigned to the fish farm influence. Particularly no microbial mats, no azoic and/or anoxic conditions, no mass abundance of opportunistic species have been observed.

Tab. 4: Summary of benthos samples:

Station	**Sampling date**	**Water depth (m)**	**No.of species**	**Abundance (Ind m^{-2})**	**Diversity (Hs)**
F Serai / C	2005	7,5	16	1992	2,48
F Serai / E	2005	5,6	11	1299	2,25
Ref. 1	2005	4,8	15	1559	2,66
Ref. 2	2005	7,0	24	3725	2,82
FF Lab / W	2005	12,0	9	1386	2,01
FF Lab / C	2005	10,5	19	2685	2,66
FF Lab / S	2005	12,0	5	953	1,29
Ref. 3	2005	10,5	8	1040	2,02
Ref. 1	10.05.06	6,0	7	953	1,85
Ref. 2	10.05.06	6,0	4	433	1,33
Ref. 3	13.05.06	7,5	19	1906	2,9
F Serai / C-W	07.05.06	6,7	22	2599	2,93
FSerai / W	09.05.06	7,5	17	2079	2,73
FSerai / N	09.05.06	7,5	13	1386	2,51
F Serai / E	06.05.06	4,7	21	2339	2,97
F Serai / C-E	12.05.06	6,0	14	1559	2,58

4. Discussion

Emission, sedimentation, deposition

The fish farming activities result in a strong input of organic material into the natural system, mainly due to fish faeces and uneaten food. Van der Wulp (2006) estimates the total emission of particulate carbon from fish farm Siuliung to be 2900 kg per month resp. 95 kg per day. The mean areal emission from the fish farm (the dimensions of FF Siuliung are approx. 100 *

30 m) would thus account for 318 g C m^{-2} d^{-1} , a number considerably higher than the estimate of Róisín Niederndorfer (2006) of 7,3 g C m^{-2} d^{-1} which was based on sediment trap results of the same area. Even lower is the estimate of Krost of 1 – 2 g C m^{-2} d^{-1} derived from decomposition rates.

The most probable explanation for the difference between emission, sedimentation and deposition is the influence of currents. Particulate organic material is released in large quantities from the fish farm; it gets dispersed in the water column and removed by strong currents from the sea floor.

During several dives the author observed a heavy sedimentation of organic particles such as scales, fish bones, uneaten fish tissue (from feed fish) and large quantities of faeces from the fish farm, particularly during feeding periods. It was also observed that large particles, including entire bodies of dead fish were moved from the sediment surface and disappeared when tidal currents began. Although no dives under fish cages were undertaken when tidal currents reached their maximum due to safety considerations, it is very likely, that sedimented material is completely removed from the sediment surface unless it is incorporated into the sediment by benthic animals. This assumption is also strengthened by the fact that the sediment surface appeared completely clean when the currents decreased in intensity and diving was possible again.

Regardless of the fact that currents remove the vast majority of particulate material from the sediment below the fish cages, a reduction of organic input will be beneficial for the entire coastal ecosystem. By improving the feed efficiency, the farm could be operated in a more efficient way with the following positive effects:

1. excess food spill will be minimized
2. costs for feeding will be reduced
3. the amount of fish catch needed for feed fish is reduced, and thus the undesired side-effects of fishing

Intensified research on feed demands and improved aquaculture techniques is required, possibly by focussing on fewer species.

Detection and prevention of cumulative effects:

Despite the fact, that the existing fish farming activities do not impose a threat to the seafloor at the present state, a cumulation of farms in the area might change that picture. Too high a density of fish farms in the neighbourhood might lead to a pre-pollution of the incoming water, thus decreasing the flushing and cleaning effect of tidal currents. This cumulative effect of multiple sources of pollution will impose a severe problem when the load of deposited particulates exceeds the capacity of sediment to decompose it, i.e. approx. 2 g C m^{-2} d^{-1}. Measurements of sediment parameters, such as a long term assessments with sediment traps near the sea floor, would be an easy way to check the potential risk and to help decision makers to arrange fish farms in a sustainable way.

The question of cumulative effects does not only refer to fish farming. There are other - and possibly more severe! - anthropogenic stressors in this region. It could be documented that the corals in the study area are in bad condition (Hoppe & Krost in prep.). It cannot be excluded that they might have suffered from the fish farm operation; but the fact, that even in a distance of 6 km from the fish farm corals showed strong signs of deterioration, indicates that the cause for coral decline must be assigned to factors of larger regional influence. Moreover, the water in the study area is very turbid. A possible explanation - which is in perfect agreement with the opinion of the local population as well as with a UNEP report - is the extensive bauxit mining activity in the region, which leads directly to a massive sediment transport and – unvoluntarily but nevertheless – to deforestation and landslides, and additional organic material will thus be transported into the marine system. For the time being it is not possible to compare the extent of the various disturbances or to assign the ecological effects to them. However, regardless of the origin of the organic material, an excess load will cause an environmental deterioration in the water and on the sub-sea sediment. We therefore recommend to install a monitoring scheme which includes sedimentation measurements

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The geochemical response of sediments to organic loading from fish farming; a case study in a tidally influenced region in the Riau region, Indonesia

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1. Introduction

In the scope of the German – Indonesian project “SPICE” (Science for the Protection of Indonesian Coastal Ecosystems), numerous environmental measurements were performed in the vicinity of a fishfarm in the Riau region of Indonesia during two intense measuring campaigns. This paper focusses the effects of fish farming on geochemical properties of the marine sediments, as well as of their causes.

2. Study area

Several fish farms are l The study area is described in detail in Van der Wulp (2006). A settlement on Pulau (island) Siuliung, south of Bintan Island in the Indonesian Riau area, providing housing for approx. 30 families is prevailingly sustained by two fish farms located in a channel area between Pulau Siuliung in the North and the very small island “Pulau Serai” in the South. The whole area is subject of a very strong tidal regime, which generates strong currents several times per day (see Krost & Runte in prep.)

The bathymetry in the study area is characterised by a channel system and coastal flats, stabilized by coral reefs. The flats have a water depth between 1 and 3 meters. Most of the settlements and also the fish farms are constructed in these shallow areas. The flats stretch about 50 to 300 meters from the coast into the sea and end in an extremely sharp slope descending from 3 meters to 11 - 13 meters water depth. Maximum water depth found in the study area was 16 m.
The sediment consists of a thick grey layer of pure clay, found in the vast majority of the stations, which is usually covered by a fluffy and silty sediment surface of several cm thickness (Runte in prep.).
Two major fish farms are operating in the study area, next to several smaller units which belong to various owners. Their respective parameters such as size, operation procedures and

other farm details are summarised in Van der Wulp 2006. Both large operations were studied. For convenience, we refer to the fish farm close to Serai Island as "FF Serai", the other on the northern side of the channel and close to our expedition base as "FF Lab".

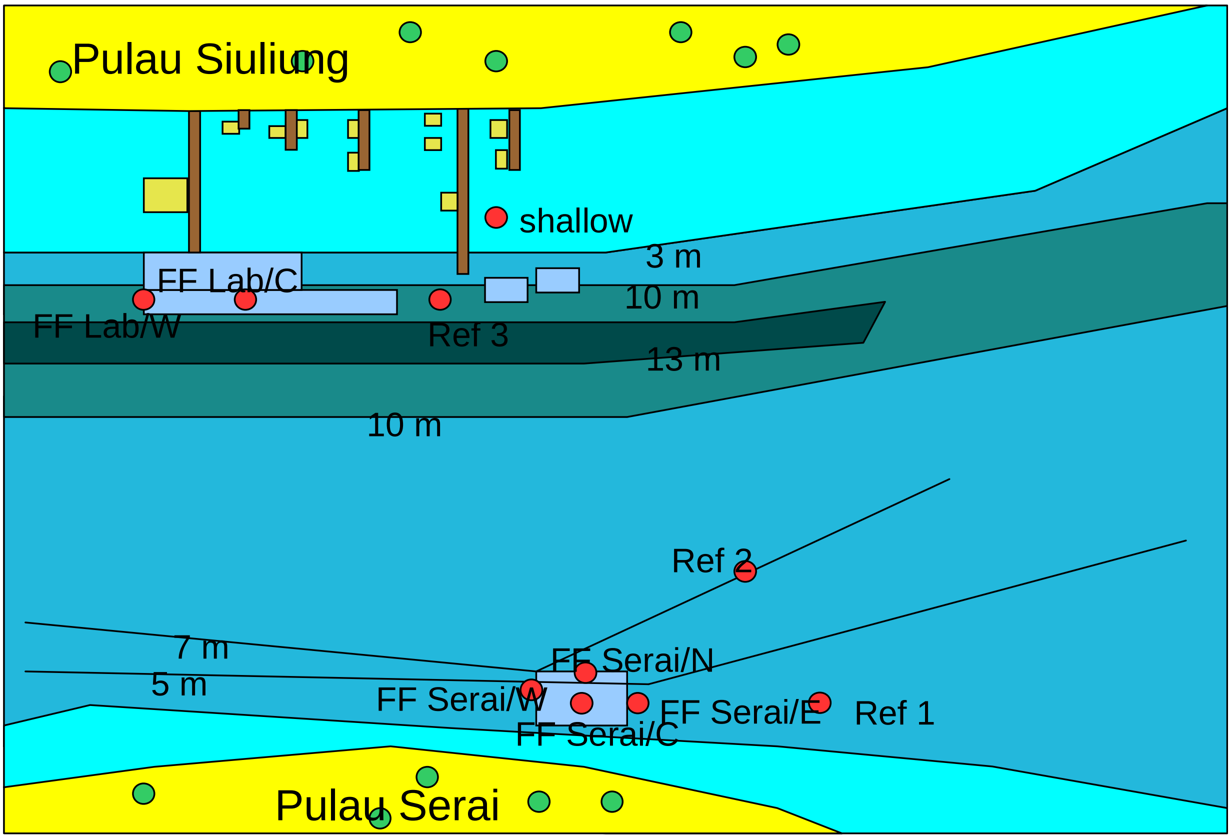


Fig. 1: Schematic visualisation of fish farms and sampling positions

3. Sampling

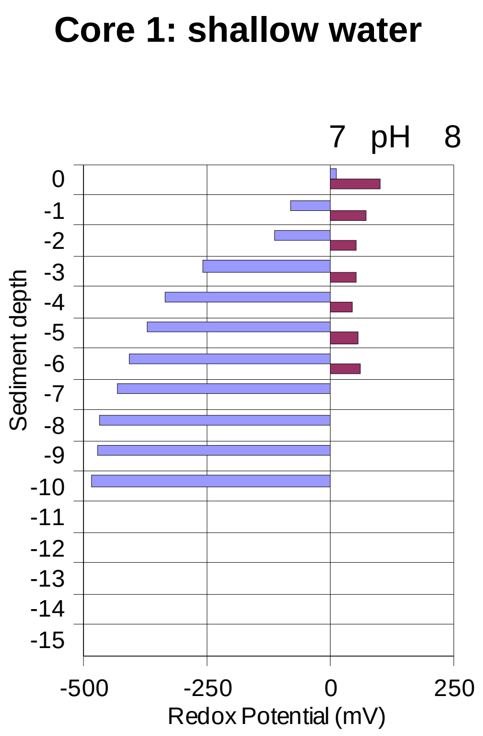
For geochemical sampling, acrylic cores of 5 cm inner diameter were inserted into the sediment by divers at the stations indicated in Fig. 1. Per sampling stations a minimum of 2 cores were taken, and analysed by electrodes for Eh and pH in the porewater, for nutrients and used for incubation experiments, see Tab. 1:

Table 1: List of geochemical samples and measurements:

Core	Date of sampling	Location	Water depth (m)	pH	Redox potential	Nutrients (NH_4^+)	Oxygen	Incubation	Grain size	Organic content (LOI)
III / 01	19.09.2005	Shallow	2.0	x	x	x				
III / 02	19.09.2005	Shallow	2.0	x	x					
III / 04	19.09.2005	FFLab C	11.0						x	x
III / 05	20.09.2005	Ref. 2	7.0	x	x	x				
III / 06	20.09.2005	Ref. 2	7.0						x	x
III / 07	21.09.2002	Ref. 3	10.5	x	x	x				
III / 08	21.09.2002	Ref. 3	10.5						x	x
III / 09	23.09.2005	FF Serai / C	7.5	x	x	x				
III / 10	23.09.2005	FF Serai / C	7.5						x	x
III / 11	25.09.2005	FF Serai / E	5.8	x	x	x				
III / 12	25.09.2005	FF Serai / E	5.8						x	x
III / 13	25.09.2005	FF Lab / W	12.0	x	x	x				
III / 14	25.09.2005	FF Lab / W	12.0						x	x
III / 15	28.09.2005	FF Lab / W-C	12.0	x	x	x				
III / 16	28.09.2005	FF Lab / W-C	12.0						x	x
IV / 01	03.05.2006	shallow	2.0				x			
IV / 03	04.05.2006	Ref. 2	9.5				x			
IV / 04	04.05.2006	Ref. 2	9.5				x			
IV / 05	04.05.2006	shallow	2.0				x			
IV / 06	06.05.2006	FF Serai / E	5.8		x		x			
IV / 07	06.05.2006	FF Serai / E	5.8		x		x			
IV / 08	06.05.2006	FF Serai / E	5.8					X El		
IV / 11	07.05.2006	FF Serai / C	7.5					X El		
IV / 18	10.05.2006	Ref. 2	7.0					X El		
IV / 19	11.05.2006	FF Lab / W	12.0					X El / Wi		
IV / 20	11.05.2006	FF Lab / W	12.0					X Wi		
IV / 21	12.05.06	FF Serai / N	4.5					X Wi		
IV / 22	12.05.2006	FF Serai / N	4.5					X Wi		
IV / 23	12.05.2006	FF Serai / N	4.5					X Wi		
IV / 24	13.05.2006	Ref. 2	7.0					X Wi		
IV / 25	13.05.2006	Ref. 2	7.0					X Wi		
IV / 26	13.05.2006	Ref. 2	7.0					X Wi		

EH- and pH- profiles

Eh and pH measurements were performed by inserting Ingold electrodes linked to a WTW pH meter into the sediment. The redox electrode allowed a maximum sediment penetration depth 13 cm, the pH electrode was restricted to 7 cm. The following graphical examples show the depth distribution of redox potential (blue) and pH-value (red). Particularly at the shallow water site (core 1) the vertical gradient of redox potential is extremely steep, indicating strong geochemical activities in the sediment. Also pH drops from around 8 in the overlaying water to approx. 7.5, a value which is rather low for marine systems and which indicates the presence of oxidising agents such as CO_2, H_2S and others.



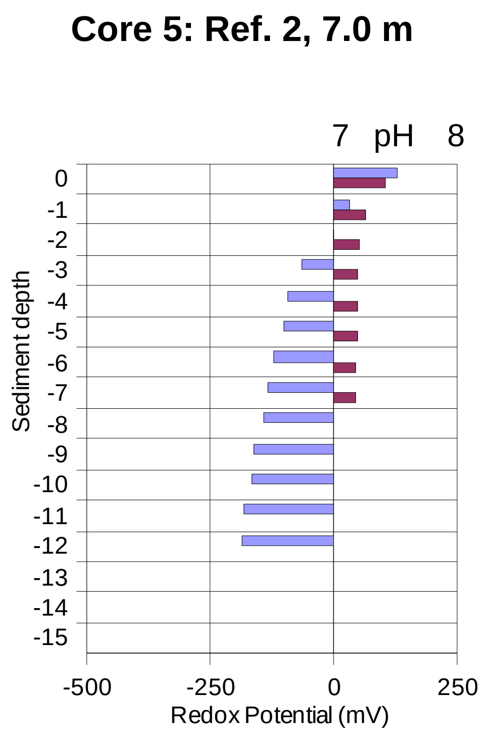


Fig. 2 & 3: Vertical profiles of redox potential (blue) and pH value (red) in sediments exposed to high organic input (Fig. 1, left) and lower organic input (Fig. 2, right)

Nutrient profiles

For analysis of porewater, the sediment was carefully moved upward within the sampling cores and sectioned in horizontal slices. The sediment slices were eluated by adding 3 volume units of distilled water to one volume unit of sediment and shaking the mixture for one minute. After about 1 to 2 hours the supernatant water was clear again, it was analysed by colorimetry for oxidised nitrogen (nitrite + nitrate) and for ammonia (NH_4^+) after filtration. Seven cores were analysed for nutrients in September 2005. The predominant nutrient compound was NH_4^+, while the concentrations nitrite and nitrate rendered to be too low to be measured with accuracy under the given expedition conditions. Core 1 shows the distribution of NH_4^+ in the pore water in shallow water (2 m), very close to the village. A prominent peak of NH_4^+ concentration in a sediment depth of 4 to 5 cm indicates a high turnover of organic material. The sediment of this sampling station is black, has a strong odour of hydrogen sulphide and is obviously anoxic due to organic pollution.

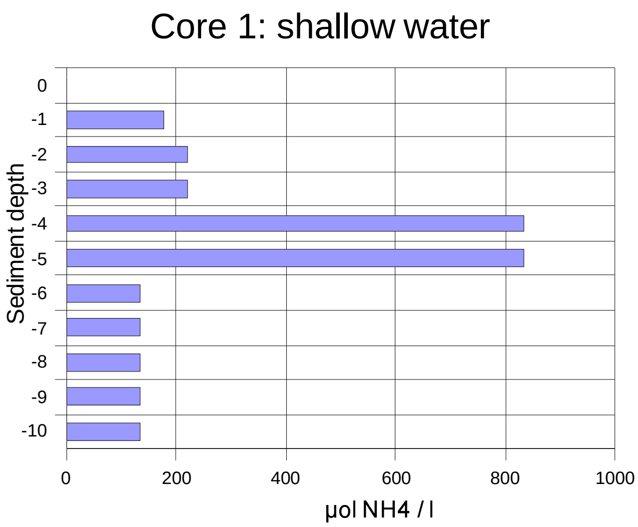
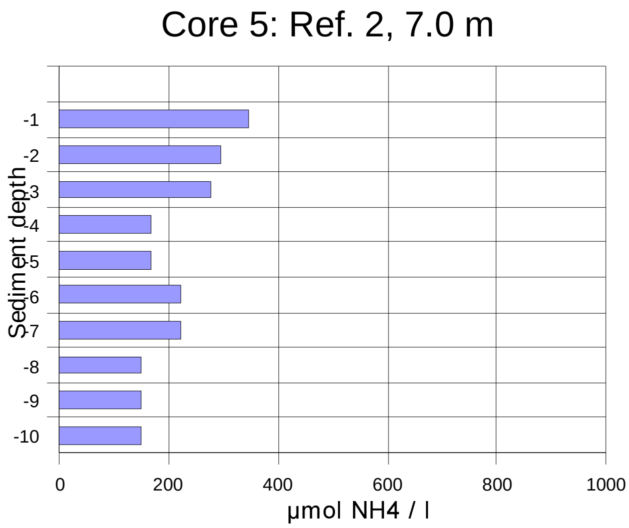


Fig. 4: Vertical profile of ammonia concentration in the porewater of shallow water station

At reference station 2, in a water depth of 7 meters, a more gradual decline of NH_4^+ concentration with sediment depth is encountered. Core 7 from reference station 3 shows a significant concentration of NH_4^+ in the porewater in the top 3 cm of the sediment, while no NH_4^+ was detectable below.



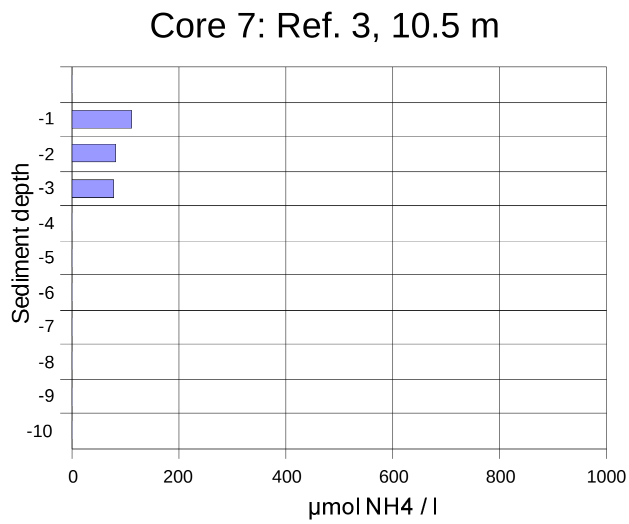
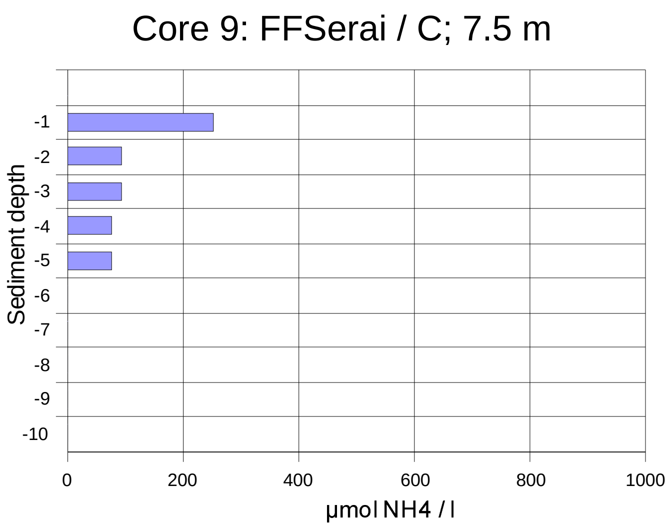


Fig. 5 & 6: Vertical profiles of ammonia concentration in the porewater of reference stations 2 and 3

A similar pattern, however with higher surface values, was found underneath the central part of fish farm Serai at a water depth of 7.5 m. At the eastern end of the fish farm elevated porewater levels were detected down to a depth of 10 cm, with maximum values between 3 and 7 cm sediment depth.



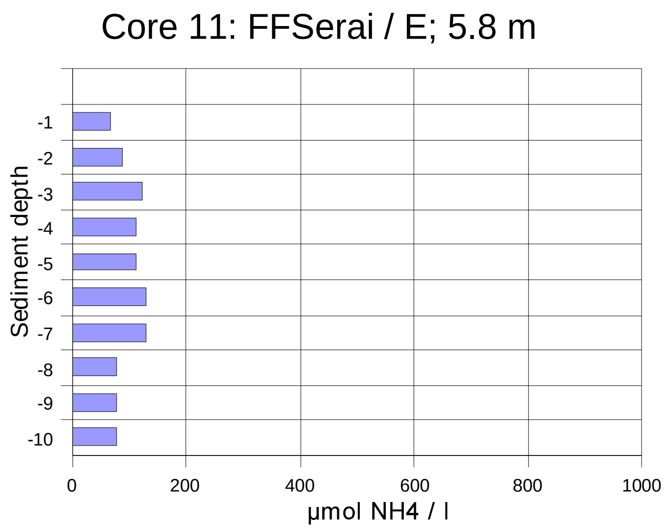


Fig. 7 & 8: Vertical profiles of ammonia concentration in the porewater underneath the fish farm Serai

At fish farm Pulau Siuliung (FF lab), close to our field station, the sea bottom was extremely hard to sample, as most of the area was covered with almost unpenetratable coral rocks. We assume that the strong currents have cleared the sea bottom from soft deposits and prevented the deposition of soft material. Only close to the the western margin of the farm, in a water depth of 12 m, we found a stretch of sediment suitable for core sampling; the results are shown below. High ammonia concentrations in the interstitial were found here, with highest concentrations at the surface and a peak in 6 – 7 cm sediment depth.

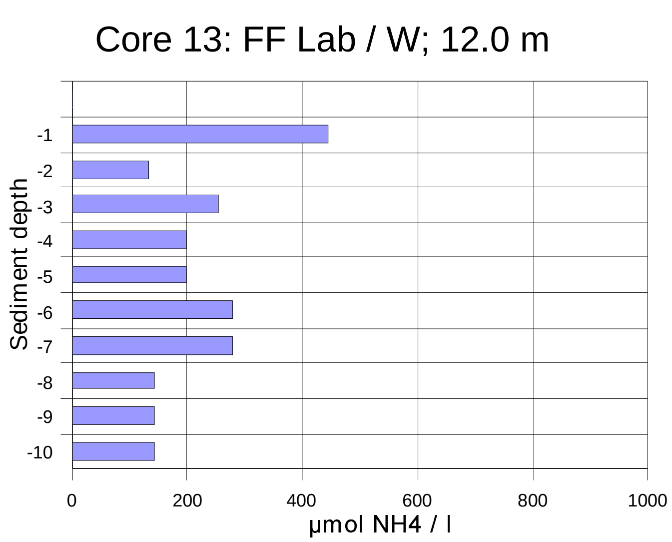


Fig. 9: Vertical profiles of ammonia concentration in the porewater underneath the fish farm Siuliung

Fluxes calculated from nutrient profiles

Porewater profiles of dissolved compounds allow the calculation of diffusive fluxes, and thus – in the case of nutrients and other compounds – also the rate of decay of the organic material by which they are released.

Fundamental for these considerations is the assumption, that the presence of NH_4^+ is caused by the decay of organic material containing nitrogen compounds. The concentration of NH_4^+ in the porewater therefore is a function of:

3. the rate of production of NH_4^+ (decay of organic material) and
4. the rate of removal of NH_4^+

Within sediments, uptake of ammonia by autotrophous organisms can be neglected, thus rendering diffusion and bioturbation the only cause of removal of NH_4^+.

The here presented calculations of fluxes are based only on the diffusional flux, while bioturbation appears to be of minor importance in the sediments encountered in the study area (Krost & Hoppe, in prep.); still: the flux calculation remains a minimum estimate.

The calculation follows Fick's first law:

$$F = -D * dC / dx$$

with:

F = Flux (in µmol * m^{-2} * d^{-1})

D = Diffusional constant of the particular ion

C = concentration of the ion (in µmol * dm^{-3})

x = distance (in cm)

The diffusional constant D has to be corrected for temperature, salinity, and for the so called "tortuosity" (Berner 1971, Lermann 1975), a factor which makes the constant suitable for sediments by taking into acccount the deviations caused by the sediment particles.

For the 6 profiles we get the flux, and – considering the ratio of carbon / nitrogen in living tissue - also the organic matter decay rates as shown in table 2:

Table 2: Sediment characteristics, ammonia flux rates and organic matter decay rates of sediment samples from

Core #	**1**	**5**	**7**	**9**	**11**	**13**	**Comments**
Sampling position	shallow	Ref. 2	Ref. 3	FF Serai/C	FF Serai/E	FF Lab/W	
Porosity in topmost cm	0.8	0.8	0.8	0.8	0.8	0.8	
$D_{sw\ 25°}$	19.8	19.8	19.8	19.8	19.8	19.8	Li & Gregory 1974
$D_{sw\ 28°}$	21.07	21.07	21.07	21.07	21.07	21.07	
$D_{sed\ 28°}$	13.49	13.49	13.49	13.49	13.49	13.49	
Flux of NH_4^+ across sediment water interface	11339.8	6414.46	2061.79	4639.03	1237.07	8247.16	
C / N ratio	17.5	17.5	17.5	17.5	17.5	17.5	Angel et al. 1995
C_{org} decay (mmol * m^{-2} * d^{-1})	198.45	112.25	36.08	81.18	21.65	144.33	
C_{org} decay (g * m^{-2} * d^{-1})	2.38	1.35	0.43	0.97	0.26	1.73	

4. Discussion

In a steady state situation (steady sedimentation of organic matter onto a sediment surface and steady decomposition rates), NH_4^+ – porewater profiles show a more or less linear increase with sediment depth (Krost 1990), or remain close to zero through the entire sedimentprofile. The shapes of the NH_4^+ profiles measured in this study cleary indicate a non-steady-state situation: highest ammonia concentration were found close to the sediment surface followed occasionally by a subsurface peak, while ammonia concentrations in deeper sediment layers were lower. It can be concluded that a significant increase of organic matter to the seafloor must have occurred, causing the inverted porewater profiles of NH_4^+.

Comparison of profiles of various distances from the fish farm did not show any clear patterns or trends, and it remains very improbable that fish farming is the main course of the variability of the results. The profile of reference station 3 (core 7) for example shows similar surface-porewater concentrations of NH_4^+ as core 11 (fish farm Serai), even though this station is further away from the fish farming activities than any other sampling station.
However, it has to be mentioned that in the vicinity of human settlements higher concentrations of ammonia in the sediment were measured (cores 1 and 13).
While in a steady state situation there is only an upward diffusional flux of dissolved nutrients, this is not the case for inverted porewater profiles (decreasing concentrations from the sediment surface to deeper sediment layers): the concentration gradient causes an additional diffusional flux downwards into deeper sediment layers! Of course, the downward flux is slower than the upward flux, due to the higher porosity of the deeper sediment layers, but ammonia concentration peaks 3 – 7 cm below the sediment surface (as for example encountered in cores 1, 5, 11 and 13) may be explained by this effect as shown in the following example:
A stochastic supply of organic material, caused for example by occasional sedimentation or occasional stillwater situations, which allows the ingestion of sedimented organic material into the sediment by its inhabitants, will initially cause a high concentration of organic material and its decay products very close to the sediment surface. Subsequently the dissolved compounds will decrease by diffusion, predominantly into the water column, but to a smaller extent also into deeper sediment layers following the concentration gradient.

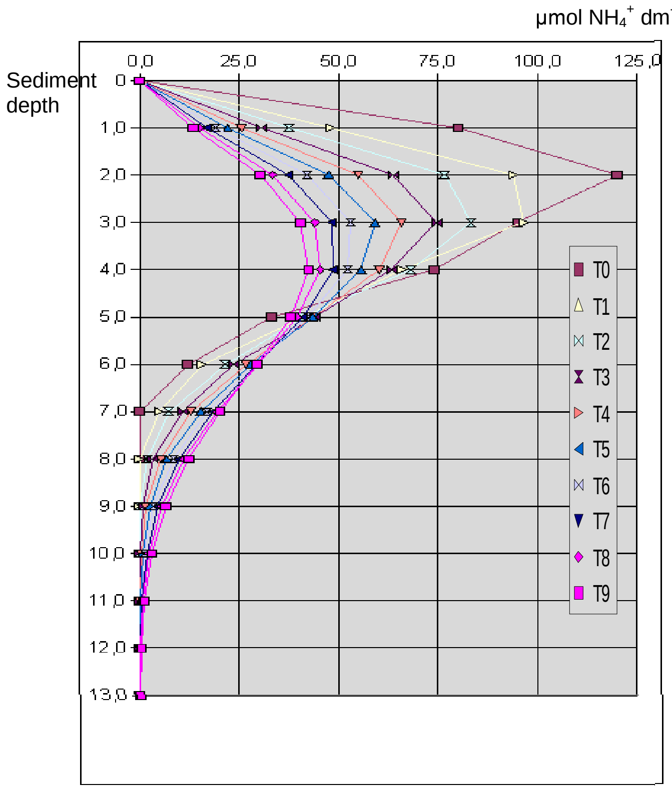


Figure 10 follows a (fictive) NH_4^+ profile (T0) over 9 days (T1 – T9), using the same constants, assumptions and conditions as above. For each consecutive day, the new porewater concentrations were calculated according to Fick's first law. It becomes apparent, that the ammonia peak decreases while it moves from the initial depth of 2 cm down to 4 cm.

Fig. 10: Calculated diffusive change of a NH_4^+ profile in the porewater over 10 days

Incubation experiments

A different and independent way to estimate benthic turnover rates is the direct measurement of the oxygen uptake of the sediment, usually called SOD (sediment oxygen demand). If possible, large enclosures (“flux chambers”, “bell jars”) directly placed in the natural environment should be preferred in order to minimize disturbance and margin effects. The approach used here was laboratory incubations, a method which makes repeated measurements easier, particularly, where sampling (diving) is inconvenient and dangerous.

Methodology

The acrylic diver cores containing approx. 15 cm of the original overlaying water were placed in the laboratory. The initial oxygen concentration was measured by needle electrodes and verified by Winkler titration. The core with overlaying water was then covered by a layer of at least 2 cm of paraffin in order to prevent gas exchange through the water surface and covered by a light-tight cover. In the first experiments, the decrease of oxygen was measured either periodically by electrodes; due to a equipment failure, for the remaining experiments Winkler titration at the beginning and at the end of the experiment was performed.

The decrease of oxygen content of overlaying water was corrected for the water volume and calculated for unit time and sediment area.

Oxygen consumption reflects not only the oxic decay of organic material in a defined system, but also the subsequent oxidation of other H^+ acceptors (nitrate, manganese, sulfate etc.) which occurs in oxygenated bottom near water in the same rate as the efflux of these compounds from the sediment. SOD thus serves as a bulk parameter of benthic turnover processes. While, however, a sufficient supply of oxygen in the natural environment of the study area was always provided (oxygen saturation was always and in all water levels close to saturation), the same prerequisit is not provided in an enclosure experiment; therefore, the oxygen consumption decreased from initial high levels following an asymptotic curve as shown in the following figure.

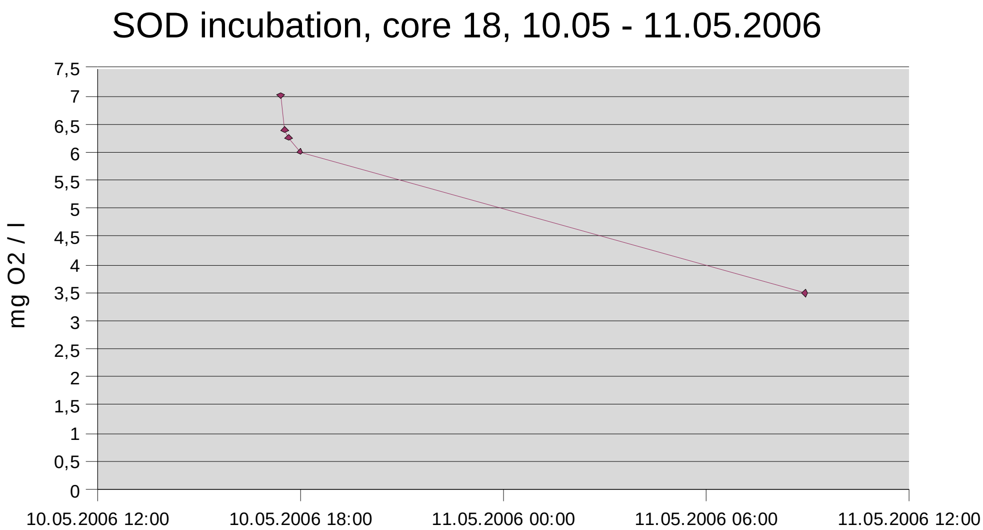


Fig. 11: SOD incubation experiment: decrease of oxygen concentration in the overlaying water during 24 hours

Repeated measurements with electrodes make it easy to define the initial slope, as shown in the following example from core 19:

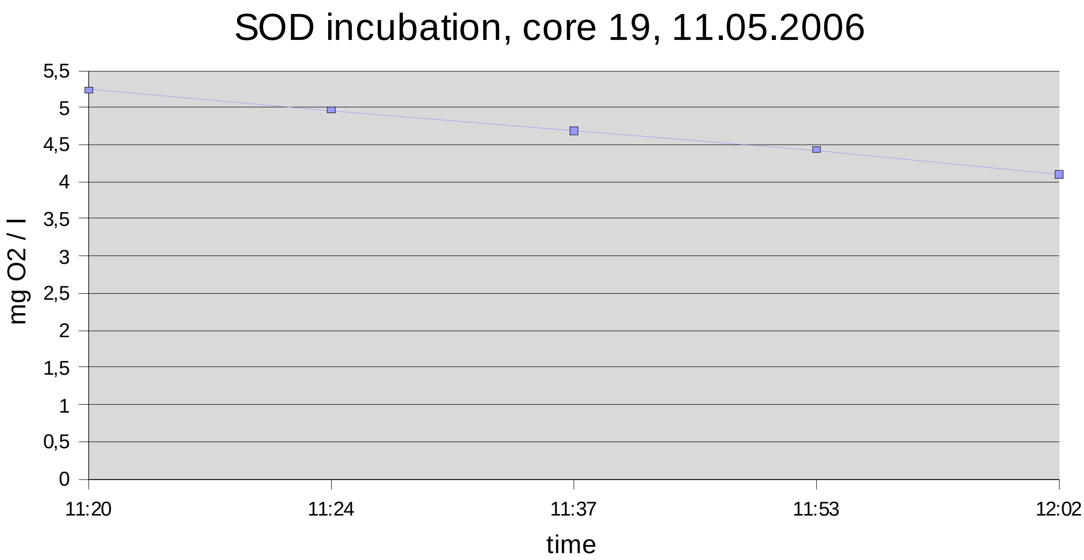


Fig. 12: SOD incubation experiment: decrease of oxygen concentration in the overlaying water during the first hour of experiment

Based on these findings, experiments were stopped after 2 – 4 hours, according to the height of supernatant water in the cores. The following table shows the results of all 10 incubation experiments.

Table 3: Incubation experiments

Core #	Date of sampling	Location	Water depth	method	SOD ($g\ O_2 * m^{-2} * d^{-1}$)	C_{org} decay ($g\ C * m^{-2} * d^{-1}$)
8	06.05.2006	FF Serai / E	5.8	electrode	3.7	1.39
11	07.05.2006	FF Serai / C	7.5	electrode	3.36	1.26
18	10.05.2006	Rference 2	7.5	electrode	1.24	0.47
19	11.05.2006	FF Lab / W	12.0	Winkler titration	1.05	0.39
20	11.05.2006	FF Lab / W	12.0	Winkler titration	0.68	0.26
21	12.05.06	FF Serai / N	4.5	Winkler titration	2.32	0.87
22	12.05.2006	FF Serai / N	4.5	Winkler titration	1.3	0.49
23	12.05.2006	FF Serai / N	4.5	Winkler titration	2.04	0.77
24	13.05.2006	Ref. 2	7.0	Winkler titration	0.69	0.26
25	13.05.2006	Ref. 2	7.0	Winkler titration	0.9	0.34
26	13.05.2006	Ref. 2	7.0	Winkler titration	0.73	0.27

5. Summary and conclusions

The concentrations of ammonia in the porewater in sediments under the fish farms were very low, despite the fact that a large quantity of organic material is released by the farm (Róisín

Niederndorfer 2006). No clear trend of porewater concentrations and redox potential was found, that would significantly correlate with the distance from this source of emission.

A reasonable match between different and independent approaches in determining rates of organic turnover were found. Highest organic matter decay rates – which coincide with highest organic residues in the sediment (Runte in prep.) – were 1.5 to 2.4 g C * m^{-2} * d^{-1}, while lower values were calculated for the margins of fish farms and reference sites.

Except for the shallow water station next to the settlement, all sampled sediments were oxic; no indicators of anoxia or hypoxia (for example smell of sulphide, or the existence of mat-building, sulphide oxidizing bacteria of *Beggiatoa*-type, absence of fish, changes in the epibenthic life) were found. Moreover, the benthic community under the fish farms did not differ substantially from the community of reference sites (Hoppe & Krost in prep.) Considering the fact that the eutrophic sediment close to the village with all indications of anoxic conditions had an estimated decay rate of 2.38 g C m^{-2} * d^{-1} it can be concluded, that the calculated rates of the other stations are rather close to the potential of oxic degradation of organic material. In order to manage the fish farm in a sustainable way – i.e. by by avoiding negative eutrophic imprints on the underlying seafloor - it is of utter importance, that the sedimentation of organic material does not exceed the degradation potential. We therefore conclude, that sedimentation rates of more than 1.5 g C m^{-2} * d^{-1} should be avoided.

In the situation of the Siuliung and Serai fish farms, the very strong tidal currents prevent extended deposition of organic material from the fish farms; the sediment therefore is relatively void of organic overloading despite the considerable emissions from the fish farm above. The hydrographic regime renders the location of the fish farms to be favourable.

6. References

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Influence of a fish farm on the benthic community; a case study in a tidally influenced area in the Riau region, Indonesia

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1. Introduction

The benthos study was part of an integrated research plan in the "Science for the Protection of Indonesian Coastal Ecosystems (SPICE)" project. Aim of the project was to investigate the effects of fish farms on the environment and to develop a decision support system for the establishment and sustainable management of such operations. It was expected that fish farms do influence the benthic communities below the fish cages by fish faeces and leftovers from feeding. Depending on the amount of organic particles to be deposited, stimulating as well as detrimental effects are possible.

2. Study area

The study area was a channel between two islands, Pulau Siulung in the North and Pulau Serai in the South and has been described in detail elsewhere (Van der Wulp 2006, Niederndörfer & Runte in prep.). A settlement on Pulau Siulung provides housing for approx. 30 families and is prevailingly sustained by two fish farms. The islands are located south of Bintan Island in the Indonesian Riau region. It is noteworthy that the area is subject of a very strong tidal regime, which generates currents up to m sec-1 several times per day.
The bathymetry in the study area is characterised by a channel system and coastal flats, stabilized by coral reefs. The flats have a water depth between 1 and 3 meters. Most of the settlements are constructed in these shallow areas. The flats stretch about 50 to 300 meters from the coast into the sea and end on the northern side in an extremely sharp slope descending from 3 meters to 11 - 13 meters water depth. The fish cages of fish farm Lab are extending from the top of the slope into the channel. On the other side of the channel the slope is not as pronounced and the second fish farm (fish farm Serai) is constructed at a water depth of four to 7 m. Maximum water depth found in the study area was 16 m.

A variety of sediment patterns was found; however, the most prominent sedimentological feature was a thick grey layer of pure clay, which was found in most of the stations, usually a few centimetres below the sediment surface (Runte in prep.). The deep areas in the channel were covered by a pavement-like calcareous stone surface with debris from the village and gorgonian corals.

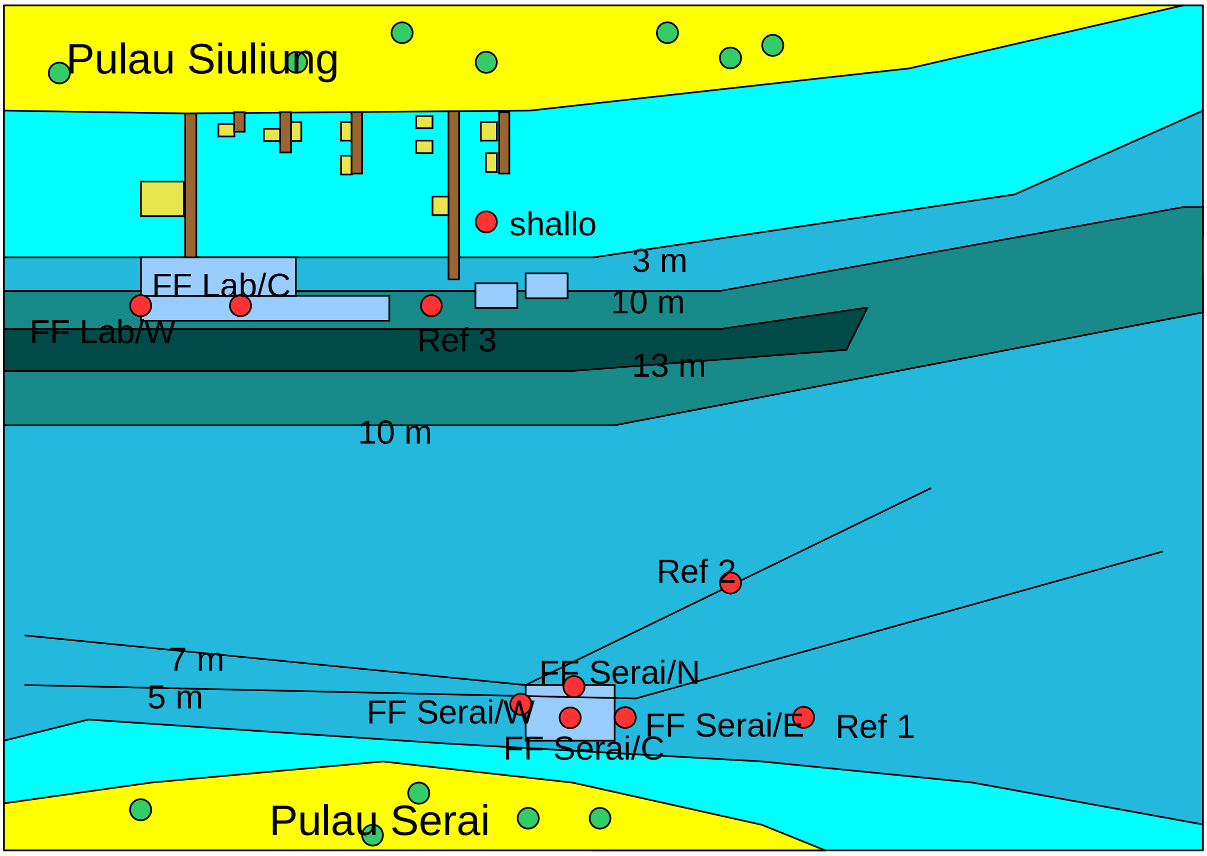

Fig. 1: Schematic visualisation of fish farms and sampling positions

Two major fish farms are operating in the study area, next to several smaller units, which belong to various owners. The size, operation procedures and other farm details are summarised in Van der Wulp 2006. Both large operations were studied. For convenience, we refer to the Fish Farm close to Serai Island as “FF Serai”, the other on the northern side of the channel and close to our expedition base as “FF Lab”.

3. Materials and methods

Fig.2: Coring below FF Serai

For sampling, acrylic tubes of five cm diameter were inserted into the sediment by divers at the stations indicated in Fig. 1. Three cores were taken at each sampling station and sampling date. The benthos samples were then sieved over 1 mm mesh size, and preserved in 4% buffered formalin solution. They were air freighted to Germany and sorted and analysed with the use of an Euromex trinocular zoom stereomicroscope at magnifications of 7 to 45. Identification was achieved by comparing specimens to keys and descriptions of North Atlantic species as well as pictures in popular photoidentification books. Most animals were identified to the family, but a few species were identical to European counterparts (i.e. *Heteromastus filiformis, Scoloplos armiger*).

4. Visual observations

The corals at the slopes were in relatively poor condition. They were visually affected by a high sedimentation load and by mechanical disturbance from boat traffic, from fishing with lines and nets and from fish farm trash. Still, the variety of coral species was surprisingly large. A number of brown algae, mainly Sargassum species, were growing on dead coral parts in the shallow water region. Below two meter water depth only blue-green algae were observed on dead corals. The channel bottom was littered with fish farm debris, but the variety and condition of the gorgonians (mainly sea whips and fans) was excellent. Only few fish were observed, some big specimens like a “tonkol” tuna were obviously escapees from the farm. A large number of fish traps was deployed under fish farm Lab, but many of those are not looked after and held trapped fish in various states of starvation. Around the net cages of both farms some fish, mainly juveniles, were observed, but their numbers was very much lower than in comparable locations (for example Nusa Karamba, Seribu Islands).

Under fish farm Serai there was a rather uniform mud area. The central position under the fish farm was approx. 7 m deep. A large number of mollusc shells were observed in an area of about 10 x 10 m in the vicinity (north) of the central station. In the rest of the area large U-shaped tubes were found in abundance. Hardly any wild living fish were noticed there, a fact that appeared to be rather surprising as the food supply for wild fish is enormous. During one of the dives a feeding period was encountered at this station. A white cloud of meat particles, scales and bones of the fish feed was sedimenting. However, there were no relicts of previous feeding to be found on the sediment surface. In May 05 mortality in both fish farms was very high due to a high silt content of the water. Below many cages dead farm fish were encountered and observed to be rolling along with the current.

Fig.3: Photo from bottom below FF Serai with dead Napoleon fish

At the eastern margin of fish farm Serai (water depth approx. 5,8 m) there was a number of Orbicular batfish (*Platax orbicularis*) and needle fish (c.f. *Crocodilian longtom*, *Tylosurus crocodilus*) (family Belonidae). The sea bottom is flat and covered with mud. There is a multitude of holes in the soft bottom almost regularly distributed, possibly the effect of the activity of sandeels.

In NE direction approaching the reference station 2 a few small pufferfish (Arothron immaculatus), including many gestating females, were found as well as small individuals of *Octopus* species in caves on a flat of approx. 5 m water depth. Further east there is a lawn of *Halophila ovalis* of at least 50 by 50 m. There were also a few anemones, but most of the sediment did not show any sign of life.

Fig.4: Immaculate Puffer (Arothron immaculatus), a common species on the mud areas

5. Benthos or Infauna

The sediments underlying Fish Farm Lab proved to be extremely heterogeneous, rendering sampling at certain positions almost impossible. Therefore, only few samples were taken, and most of benthos sampling took place underneath and in the vicinity of Fish Farm Serai as shown in Tab. 1:

Tab. 1: Summary of benthos samples:

Station	**Sampling date**	**Water depth (m)**	**No. of species**	**Abundance (Ind m^{-2})**	**Diversity (Hs)**
FF Serai / C	15.09.05	7,5	16	1992	2,48
FF Serai / E	17.09.05	5,6	11	1299	2,25
Ref. 1	18.09.05	4,8	15	1559	2,66
Ref. 2	20.09.05	7,0	24	3725	2,82
FF Lab / W	25.09.05	12,0	9	1386	2,01
FF Lab / C	19.09.05	10,5	19	2685	2,66
FF Lab / S	25.09.05	12,0	5	953	1,29
Ref. 3	21.09.05	10,5	8	1040	2,02
Ref. 1	10.05.06	6,0	7	953	1,85
Ref. 2	10.05.06	6,0	4	433	1,33
Ref. 3	13.05.06	7,5	19	1906	2,9
FF Serai / C-W	07.05.06	6,7	22	2599	2,93
FF Serai / W	09.05.06	7,5	17	2079	2,73
FF Serai / N	09.05.06	7,5	13	1386	2,51
FF Serai / E	06.05.06	4,7	21	2339	2,97
FF Serai / C-E	12.05.06	6,0	14	1559	2,58

Determination of Indonesian benthos species – as it is the case for most tropical benthos species - is rather difficult due to the lack of keys for species identification.

Fig.5: Benthos sample after sieving and sorting

Therefore, the following list (Tab. 2) will only summarise the number of species within the major taxonomic groups.

Tab. 2: Number of species and their resp. taxonomic groups

	2005	2006	Both years
Polychaeta	29	30	40
Nematoda	1	1	1
Mollusca	6	7	10
Crustacea	13	15	23
Echinodermata	2	5	5
Nemertina	2	1	2
Bryozoa	1	1	1
Porifera	1	0	1
Coelentarata	0	2	2
Sum	55	62	85

It was surprising that neither the number of species, nor the abundance of individuals per m^2 nor the diversity can be assigned to the distance respectively proximity to the fish farms. Water depth, coastal exposure and sediments were relatively similar; water depth is also to be excluded as a controlling factor for benthic ecological indices.

Fig. 6 shows the situation underneath and in the vicinity of Fish Farm Lab: Most Species and individuals were found directly underneath the farm, whereas at the margins and in approx. 30 m distance lower values were ascertained.

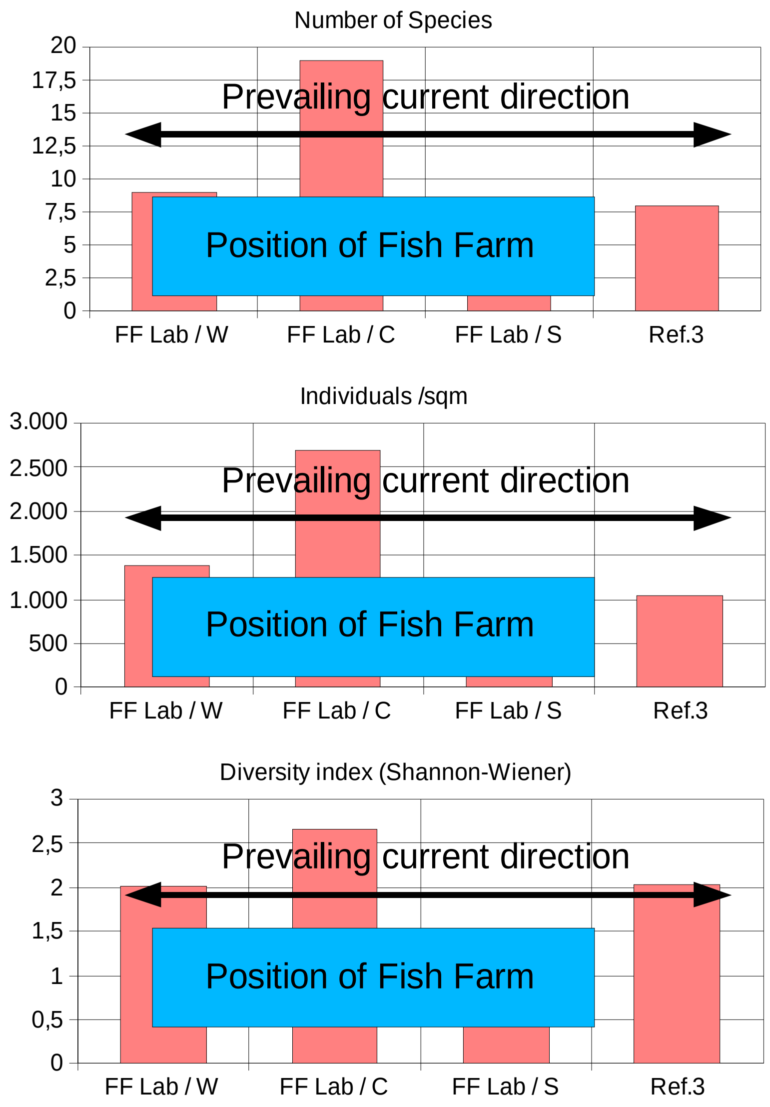

Fig. 6: Ecological indices of benthos samples underneath and in the vicinity of FF Lab in September 2005

As has been pointed out before, sampling underneath fish farm Lab was difficult. It was therefore decided to shift the sampling program to fish farm Serai. The results are shown in the following figure 7:

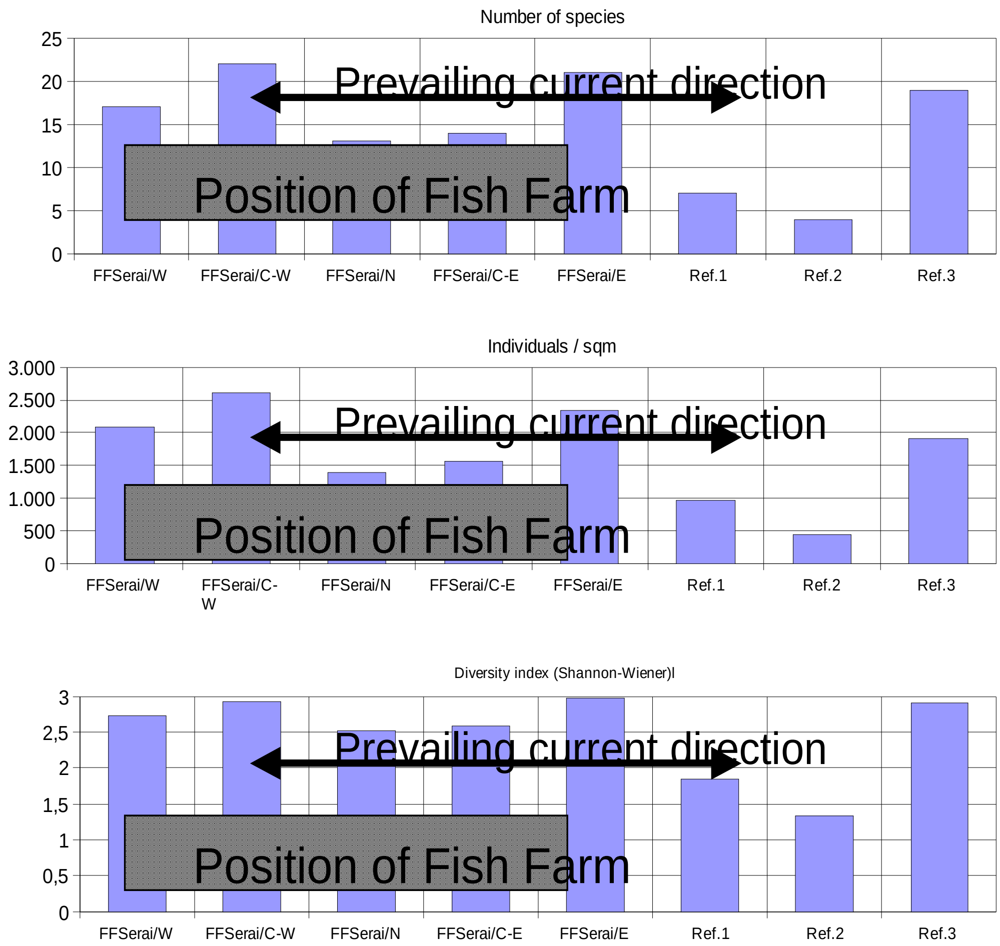

Fig. 7: Ecological indices of benthos samples underneath and in the vicinity of FF Serai in September 2005

Highest abundance, species numbers and diversity were found at a remote reference station, while at the eastern edge of the farm these indices were lower. In order to clarify the situation, fish farm Serai was extensively sampled during the subsequent expedition in April 2006. This time, reference station 2 showed a very low diversity and abundance, while the benthic coenosis shows no clear pattern underneath the fish farm. Reference station 3 refers to fish farm lab and is listed here only for the sake of completeness.

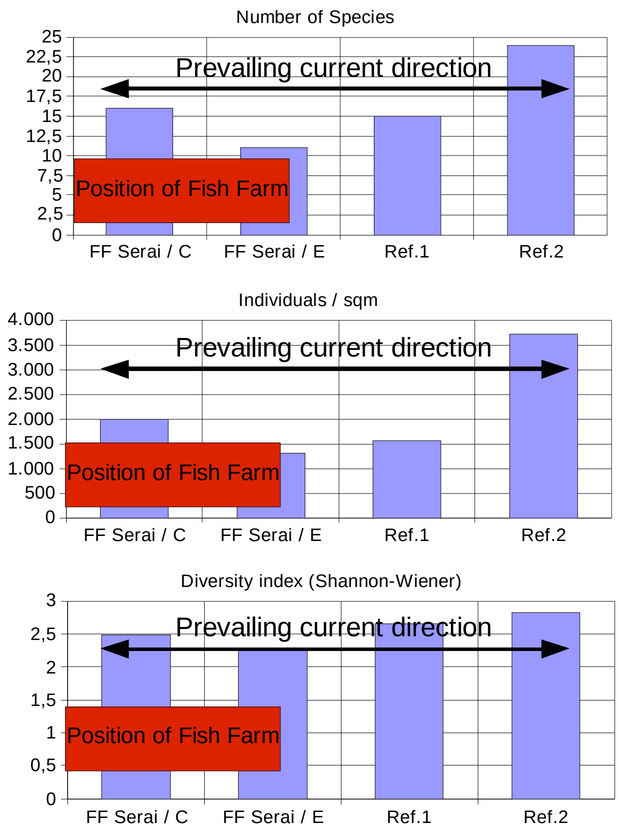

Fig. 8: Ecological indices of benthos samples underneath and in the vicinity of FF Serai in April 2006

6. Discussion

It was presumed, that an output of particulate nutrients would in a low concentration benefit the benthos community and lead to a higher biomass below the fish cages. At a higher concentration it might exceed the carrying capacity and therefore lead to oxygen deficiency and loss of biomass or diversity. However, the variation between benthos samples under or close to the fish farms and at reference stations did not exceed the variation that was found between different samples. It is therefore concluded, that despite the high input of organic material (Niederndorfer 2006), and opposed to the majority of reported situations underneath fish farms, no effects on the benthic community could be detected, which could be directly assigned to the fish farm influence. Particularly no microbial mats, no azoic and/or anoxic conditions, no mass abundance of opportunistic species have been observed. Fluid excretions, particulate matter and even large objects, like dead farm fish, are transported out of the channel system (visual observations).

The stone corals in the vicinity of the fish farm Lab are in a very poor condition. It cannot be excluded that their status has suffered from the farm operation. However, even at significant distance (approx. 6 km) the corals observed showed strong signs of deterioration indicating that the cause for decline in their health status must be assigned to factors of larger regional influence. A possible explanation is the increased turbidity in the whole region due to extensive bauxit mining (UNEP report). This agrees with the observation, that most corals in the area were more or less covered by sediments. However, in the channel with its high current speed the sedimentation affects corals to a much lesser extend. Also, the gorgonians at the channel bottom are in a very good condition, further indicating that any negative influence of the fish farm Lab do not reach the bottom. It is not clear whether the Gorgonians profit from any farm output, due to a lack of comparable stations.

Obviously, the fish farm complex is situated in an optimum position in the region. Output from the fish farm is distributed and diluted to a wide area, so that no effects on the benthos community below or close to the cages can be shown. A limitation to further enlargement of the farm complex cannot be estimated from the available benthos data.

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Numerical modeling of the holding capacity of coastal finfish mariculture in Indonesia

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Abstract

In order to guarantee environmental sustainability, the dissolved nutrient loads arising from marine fish farming activities must not exceed the holding capacity of a specific site in question. Nutrient discharge is closely related to stock size and amount of fish produced. Numerical modeling of nutrient emissions was used to support the decision making process with respect to the maximum allowable stock size of coastal cage farms in Indonesia. After validating the numerical model with field data different scenarios considering various scales of fish farm installations were examined. The holding capacity was then determined comparing the results of model simulations for ammonium immissions with acceptable limits for environmental sustainability.

1. Introduction

Impacts on Indonesian coastal ecosystems by intensified fish farming activities are becoming a problem of increasing relevance. A target of current economic policies in Indonesia is to increase the farmed fish production in the future in order to improve the local income and social welfare of the coastal population. However, fish farm implementation should not lead to a deterioration of the natural environment and should proceed in a controlled manner.

Hypernutrification caused by nutrient discharges from coastal cage farming constitutes a predominant problem because of its stimulating effects on algal growths and bloom formation. The amount of nitrogen and phosphorus released from the fish farms is linearly increasing with the stock size and amount of fish produced. In the present paper the maximum allowable size of fish farm implementation at a potential site is determined with the help of numerical model simulations. The holding capacity is defined comparing model results for ammonium imission with environmental threshold values taken from the literature.

2. Setup of the model

Water quality simulations have been carried out with Delft3D-WAQ software package. The hydrodynamic flow information is derived from the coupled two-dimensional flow module of Delft3D. The model solves the advection-diffusion-reaction equation (Eq. 1) discretely to simulate advective and dispersive transport of nutrients. The advection-diffusion equation for a two-dimensional depth integrated model may be written as:

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} - v_x \frac{\partial C}{\partial x} + D_y \frac{\partial^2 C}{\partial y^2} - v_y \frac{\partial C}{\partial y} + S + f_R(C,t) \qquad (1)$$

Where C= concentration, D_x and D_y= dispersion coefficients in the x and y directions, v_x and v_y= depth-integrated fluid velocities in the x and y directions, S= additional inflows and $f_R(C,t)$= reaction terms for processes that are described in terms of concentration and time. The discharge term S is an additional discharge which in this study represents the dissolved inorganic nutrient emission arising from the fish farms. The reaction term $f_R(C,t)$ is comprised of both physical and biochemical processes. In this study only a biochemical process, namely nitrification, is taken into account which is described in the following section.

2.1 Water quality parameters: Nitrification of ammonium

Concentrations of dissolved inorganic nutrients arising from aquaculture activities are important limiting factors that exert an adverse impact on the quality of the adjacent water body. Results of the in-situ measurements indicate that ammonium is the most abundant nutrient released (see Ladwig, this volume). In both of the investigation areas in the vicinity of the fish farms, high flushing rates are observed and confirmed by the hydrodynamic model (0.4-1 m/s). Thus, the impact on the bed sediment is disregarded. As a preliminary approach, processes like nutrient uptake by algae as well as nutrient remineralization are not considered as the temporal scale of the model simulations (3 to 7 days) are far too short for these processes to have a significant effect. Denitrification is also not incorporated in the model considering high dissolved oxygen concentration (>6 g/m^3). Nitrification is assumed to be the most important transformation process.

Nitrification is the chemical transformation of ammonium into nitrate (with nitrite as an intermediate product) under the presence of oxygen. The conversion rate is temperature and oxygen dependant (first-order nitrification). In this study nitrification is modeled as a sum of a zero- and first-order process (as the water temperature, 30°C, is higher than the critical value of 3°C). Process parameters used in the model are listed in Table1.

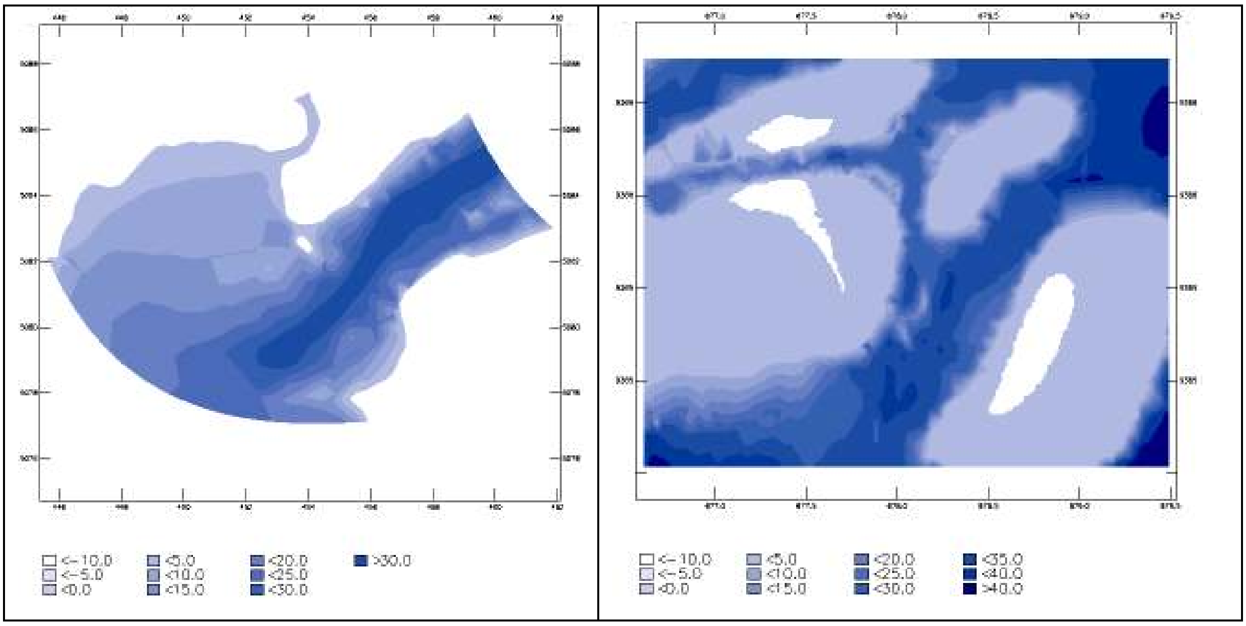
Table 1. Process parameters used in nitrification

Parameter	**Value**
Temperature coefficient for nitrification	1.07
Ambient water temperature	30°C
Critical water temperature for nitrification	3°C
Zero-order nitrification flux	0 $gN/m^3/d$
First-order nitrification rate (for 20°C)	0.1 1/d
Optimum oxygen concentration for nitrification	5 g/m^3
Dissolved oxygen concentration	6 g/m^3

A temperature coefficient for nitrification is used to modify the first-order rate for the actual water temperature. However, it should be noted that direct measurements of the in-situ nitrification rate are rare and data are mostly obtained through indirect procedures. (Capone et al., 1990). For comparison the first-order nitrification rate that has been used in modeling Singapore Straits (Tkalich et al., 2002) was considered ($k=1.66\times10^{-7}$ $1/s\approx0.01$ $1/d$). Detailed description of the numerical solution of the nitrification is given in Delft3D-WAQ manual (2003).

3. Case studies

The ability of the water quality model to represent the actual in-situ nutrient distribution is checked by comparing data from field measurements conducted in Pramuka and Serai Islands with model predictions of the concentration values. The bathymetries of the sites are presented in Figure 1. The effluent arising from the fish farms is represented as a point source in the model domain with a certain (and constant in time) discharge concentration of the relevant nutrient type. The flow characteristics derived from the hydrodynamic model is incorporated into the water quality model considering either a single tidal cycle -rewinding the representative tidal period through out the simulation period-, or by directly using the actual water level and current velocity data predicted for that period. The time step for the coupled hydrodynamic file is 30 min. The temporal resolution of the water quality model depends on the numerical method selected and the computation time required after satisfying the numerical stability of the solution of the advection-diffusion equation. It thus necessarily follows that the maximum time step allowed in the water quality model is the time step of the coupled hydrodynamic model, i.e. 30 min.



(a) (b)

Figure 1. Bathymetrical maps of the sites: a) Serai, b) Pramuka.

The dissolved nutrient load discharged from the fish farms was estimated from the stock size and type of the fish species involved with an empirical approach based on literature data on the metabolic rates of farmed fish (Van der Wulp, 2006). Calculated estimates of nutrient discharge were crosschecked with field data on nutrient emission, which were assessed by tidal measurements underneath the fish cages (see Ladwig, this volume). In this study the concentration values as calculated from the empirical formulation are considered to be in a constant rate covering the whole time period of the simulation.

Data from nutrient measurements at the open boundaries of the model domain are both used to assign the nutrient loads entering the system and the initial background values. The water body at the open boundary locations is far enough from the fish farming sites and not impacted by other anthropogenic activities.

Two water quality models have been set-up for the two areas of investigation. Sensitivity tests have been carried out for the Serai Island model because of the better data availability.

3.1 Serai Island Model

Field data taken from the third intensive measurement campaign (IMC III) have been used to set-up the open boundary and initial conditions. The open boundary nutrient conditions were defined from the in-situ tidal cycle measurements at these locations. The initial nutrient concentrations have been determined from stations far away from the influence of the fish farm. The nutrient emission arising from the fish farm has been simulated by considering the monthly average of the estimated nutrient output estimation of each individual cage cluster (see van der Wulp, this volume). Ammonium emission through a single cage cluster is calculated to be 0.007 to 0.015 gN/s, and for phosphorus between 0.0003 and 0.0006 gP/s. The numerical solution of the advection-diffusion equation has been accomplished by an implicit horizontally backward, vertically central scheme. This method uses an iterative procedure to compute the concentrations and offers some advantage over numerical schemes using direct solving methods, which may be very time consuming and requiring very high internal computer memory. Details about the numerical scheme can be found in the Delft3D-WAQ User Manual (2003).

- **Sensitivity tests**

Time step:

The time step determines the accuracy of the transport and reaction calculations. The smaller the time step, the higher the accuracy of the computations. In order to determine the optimum time step value time steps of 30 min, 15 min and 1 minute were tested. The results have been compared for ammonium concentrations predicted in the vicinity of the fish farm (Figure 2). The values differ slightly only at the highest and the lowest concentrations. Considering the high computing time required for the 1 min time step and the better accuracy achieved, a time step of 15 min is selected.

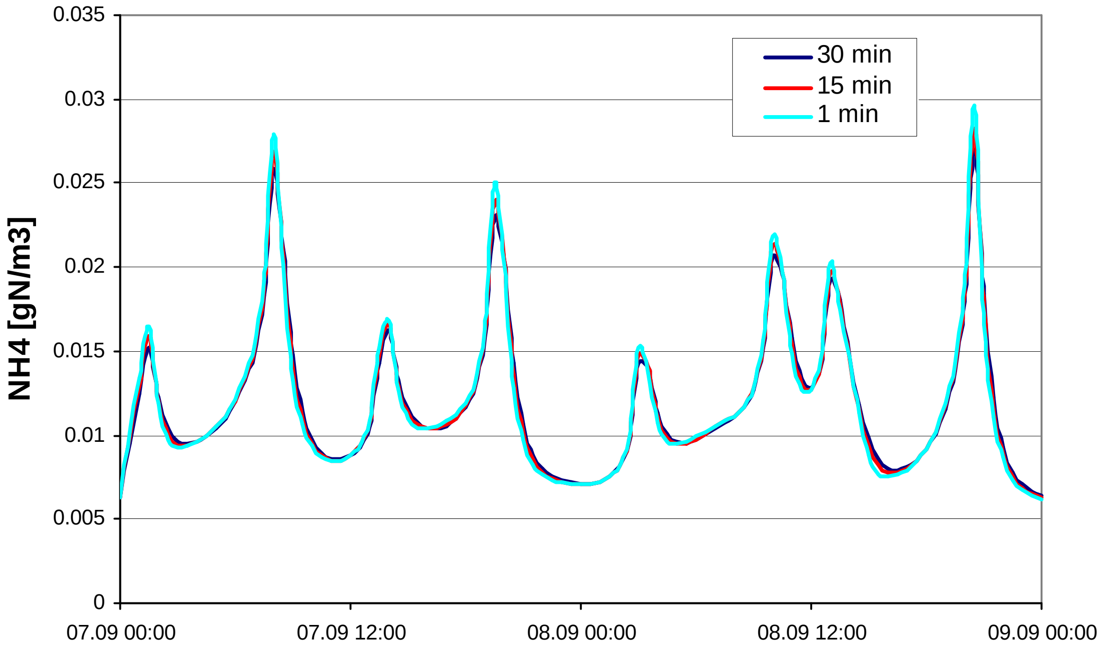
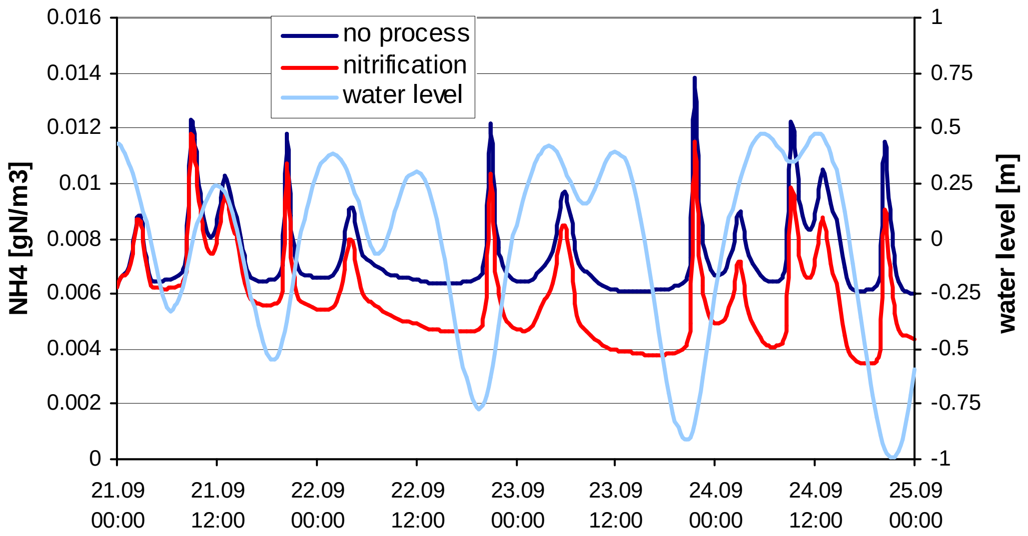


Figure 2. Influence of the time step on ammonium concentrations at the fish farm location

<u>Effect of nitrification:</u>

The ammonium emissions released from the fish farm are dispersed following the physical conditions and undergo biological and chemical transformations at the same time. As discussed before, the key process for the biochemical transformation is assumed to be nitrification of ammonium. The effect of this process is examined by comparing simulations which account for nitrification using the parameters listed in Table 1 with model runs disregarding the process. In the latter case ammonium is considered to behave like a conservative substance, i.e. only the advective transport determines the distribution of the nutrients. The predicted ammonium concentrations are shown in Figure 3 together with the water level at a site in the vicinity of the fish farm. As can be traced from the figure the peak concentrations are reached following the low water periods when the flushing rate is supposed to be minimum. In the case where nitrification has not been considered, ammonium levels are only fluctuating with respect to the tidal cycle (flood and ebb periods). Integration of the nitrification process leads to a decrease of ammonium concentrations but they remain at the same range through out the simulation period. On the other hand there is an increase in the nitrate concentration during the first two days of the study period. This phenomenon can be explained taking into account the continuous dissolved ammonium emission from the fish farm and the nitrate production through nitrification. In the case of nitrate the concentrations increased as much as 50%. Consequently, it can be stated that nitrification has a major impact on the predicted nutrient concentrations.



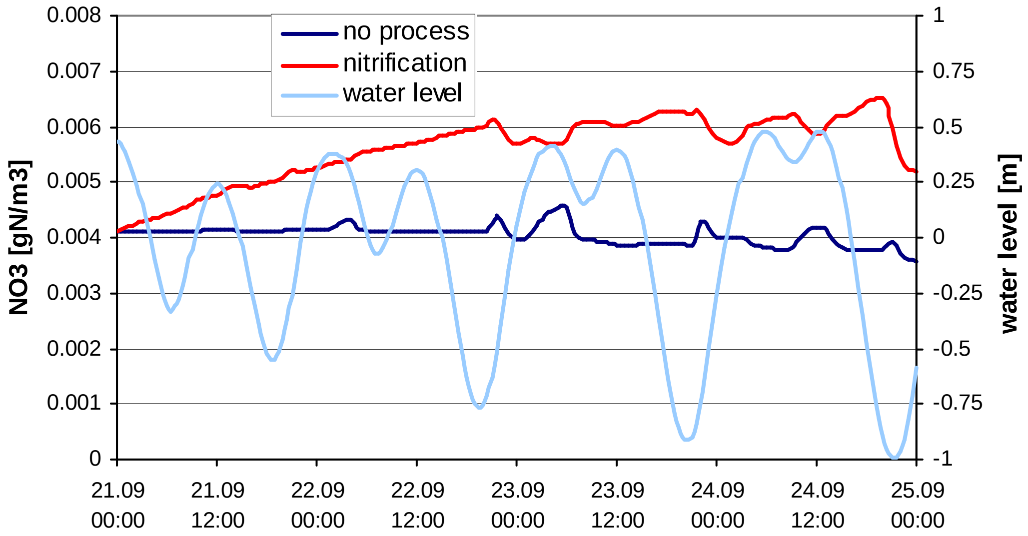


Figure 3. Effect of nitrification on ammonium and nitrate concentrations at the fish farm

<u>*Effect of water level:*</u>

An iterative loop of a representative tidal cycle period saved from the hydrodynamic data of the two-dimensional flow module of the DELFT3D model was used as hydrodynamic input to the water quality model. Since the water exchange capacity of the site in question also depends on the tidal cycle selected, two model simulations have been designed in order to check the influence of spring and neap tidal periods on nutrient advection. In Figure 4 the water level predictions used in the comparison together with the average ammonium concentrations during the corresponding tidal cycle are shown.

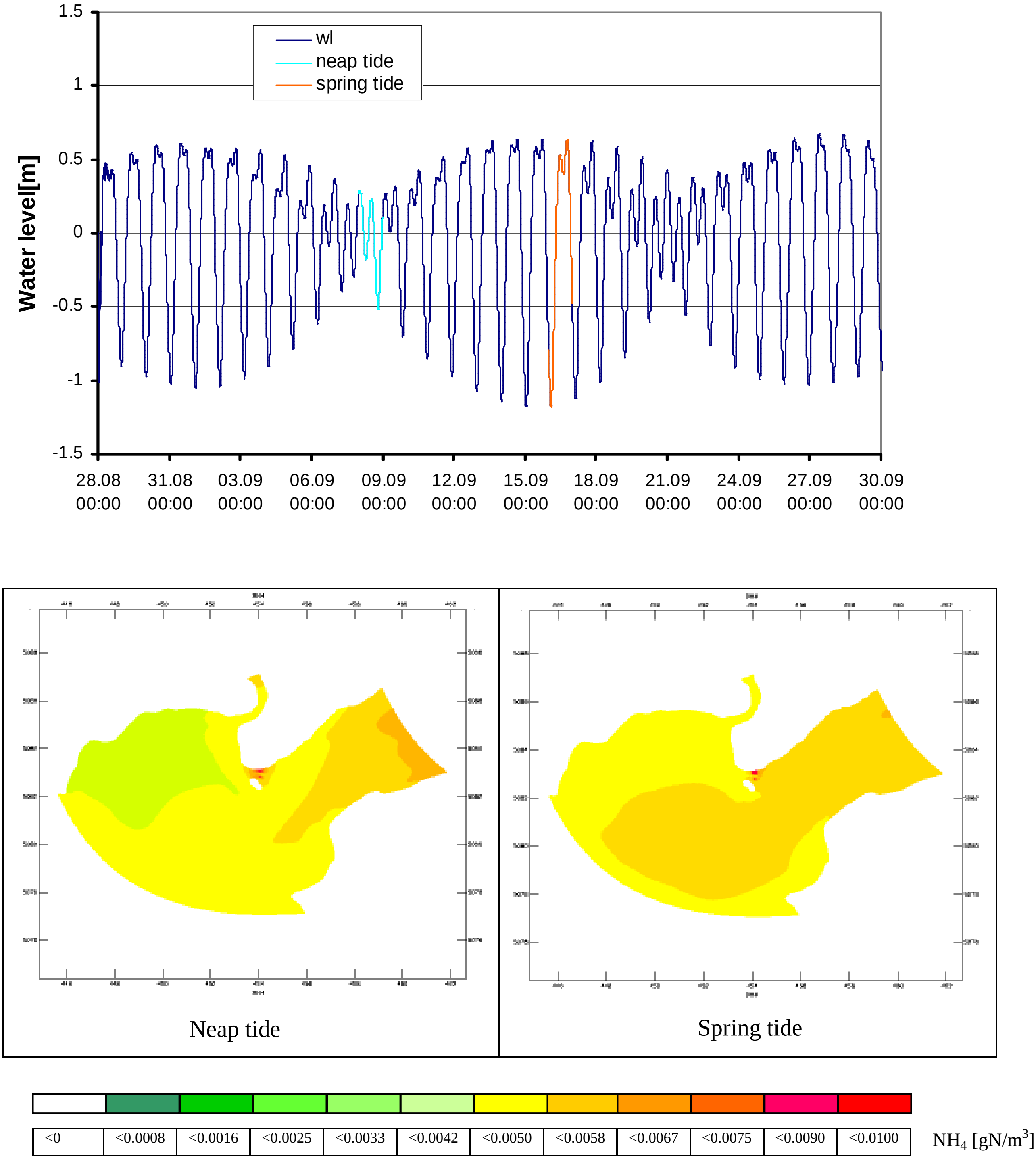


Figure 4. Ammonium concentration comparison in the model domain considering neap and spring tidal periods. The corresponding water level predictions are given in the upper figure

As the flushing capacity decreases during the neap tide dissolved ammonium is less dispersed and thus the concentrations in the vicinity of the fish farm are more pronounced. For the simulations concerning the determination of the holding capacity of the site, the worst case neap tide conditions were selected to be on the safe side.

- **Calibration with respect to nitrification constant**

Dissolved nutrient concentrations measured during the third measurement campaign (IMC III) have been compared with the model results to calibrate the first-order nitrification constant. As a first trial the default value of 0.1 d^{-1} was used as nitrification rate (Figure 5). The nitrate concentrations predicted are higher than the observed values and ammonium concentrations are lower when this value is considered. The reaction rate was thus decreased to 0.01 d^{-1} , which is in the range of values applied to a similar area in the tropics (see section 1.2). The application of this nitrification rate resulted in lower nitrate (20%) and higher ammonium concentrations (10%), which improved the accordance of model and field data.

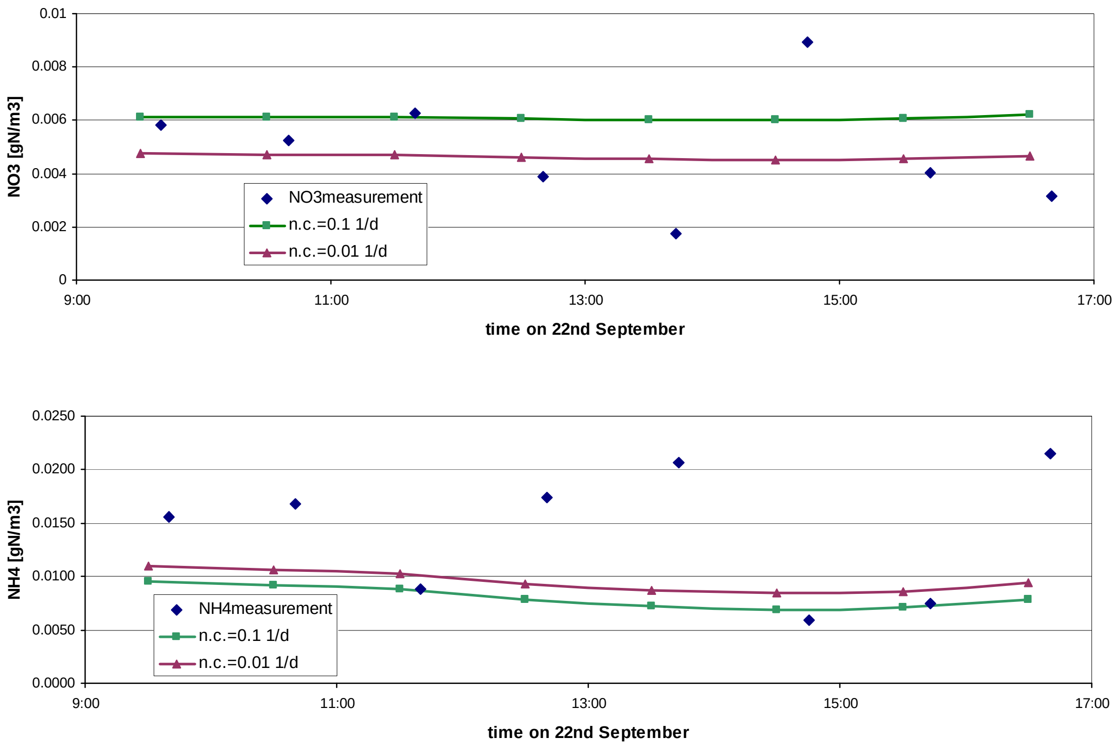


Figure 5. Measurement vs. model predictions of nutrient concentrations considering different first-order nitrification rates.

- **Model results vs. measurements**

The performance of the calibrated model has been tested on a second set of field data, which had been obtained two days after the first set at the same location (Figure 6). The corresponding predicted water level is also given in the figure. There is no clear relationship between the predicted nutrient concentration and the water level. Apart from ammonium, observed nutrient concentrations are lower than the predicted ones.

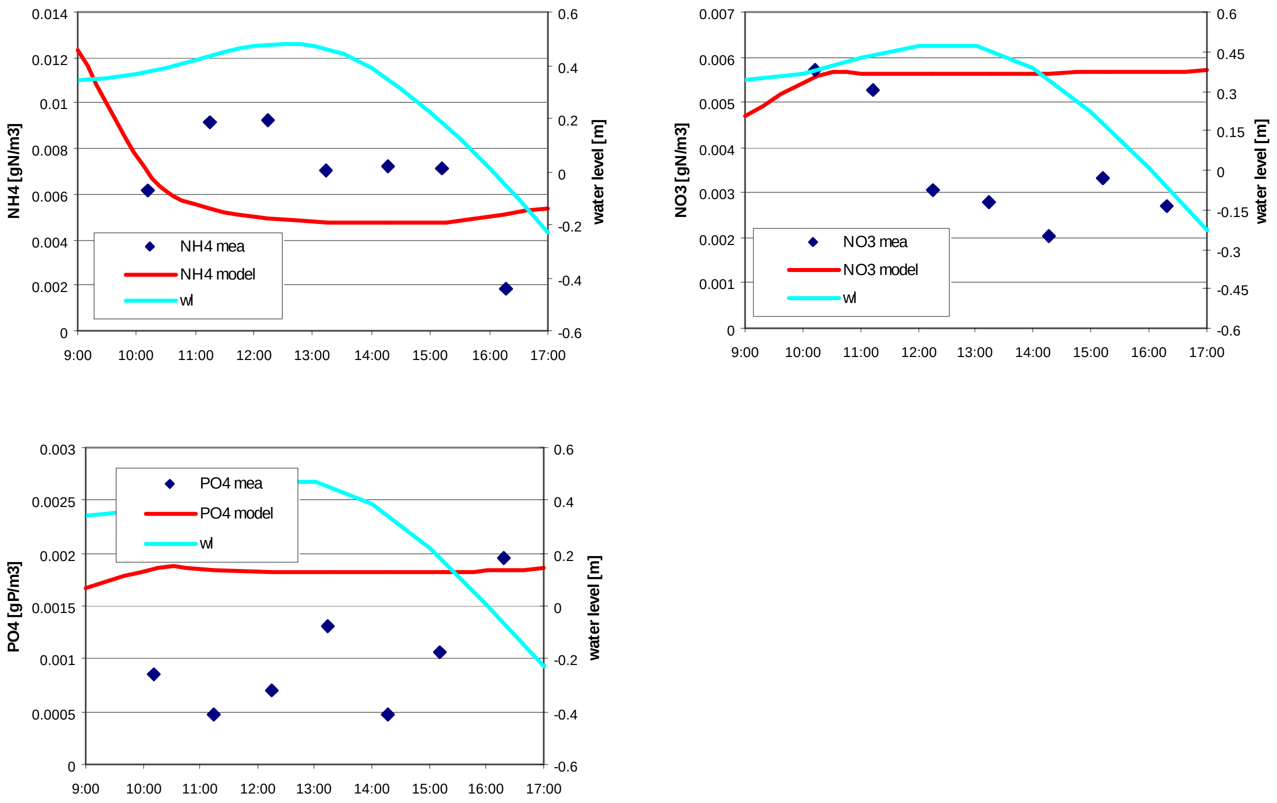


Figure 6. The measured vs. predicted nutrient concentrations after calibration in the vicinity of the fish farm.

The accuracy of the model predictions is tabulated in Table 2.

Table 2. Prediction errors

Error type	NO_3	NH_4	PO_4
Mean absolute	0.786	0.986	0.927
Root mean square	0.0024 gN/m^3	0.0030 gN/m^3	0.0001 gP/m^3

- **Determination of the holding capacity**

The water quality model with the settings as described above has been applied to the area of investigation in order to examine the potential environmental impact of a future expansion of the aquaculture activities. The estimation of the holding capacity should be based on three environmental criteria: the bottom sediment quality, the water quality within the fish cages and the water quality of the nearby water body (Stigebrandt, 2004). In this study the sediment quality was not assumed to be a critical factor due to strong currents and high bed shear stress, resulting in intense resuspension and dispersion of particulate material in the area. For the same reasons, oxygen deficiency was not a matter of concern in the study area. Therefore, in the present holding capacity analysis, the enhancement of dissolved ammonium levels was considered as a primary indicator of water quality because of the pronounced discharge of this nutrient species from the fish farms. In the model scenario, imaginary fish farm cage clusters, each consisting of 16 cages with 500 fish (tiger grouper), were placed all over the area at sites designated as ‘best suited’ in a previous suitability analysis (Windupranata, 2007) (Figure 7). To determine the maximum allowable number of cage clusters simply a trial-error procedure was applied starting from an initial virtual number of cage clusters followed by a gradual scale-up, thereby examining the resultant impact on the surrounding water body in terms of ammonium concentrations. In the simulation, each individual fish farm represented a point source in the model. Nutrient discharge rates from the farms were calculated according to van der Wulp (this volume). The analysis was carried out for the neap tidal cycle as shown in Figure 4 by averaging the ammonium concentrations in this period. The resulting ammonium concentration in the model domain is presented in Figure 8. Nutrient enhancement was compared to threshold dissolved ammonium levels as outlined in the eutrophication assessment procedure of the Oslo-Paris commission (OSPAR 2005). According to this assessment, critical nutrient levels are defined as an increase by more than 50% of undisturbed (background) concentrations. In the present study, background concentrations for ammonium were calculated from the open boundary nutrient measurements resulting in an average value of 0.0063 gN/m^3 and a threshold value of 0.01 gN/m^3, respectively.

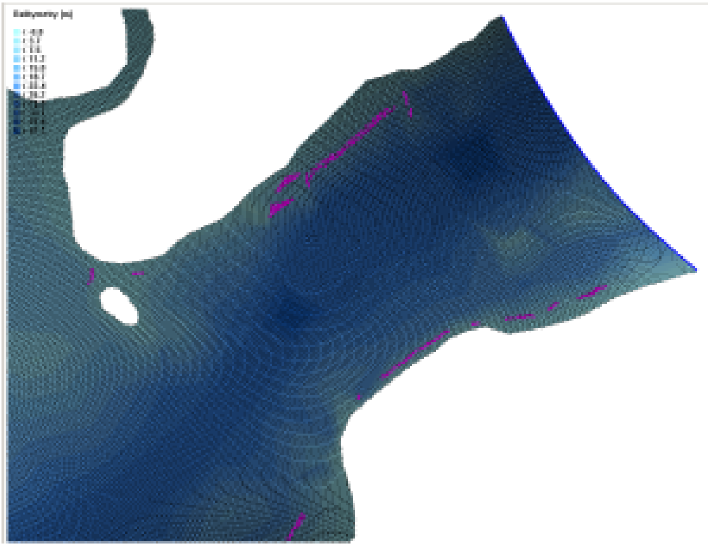


Figure 7. Location of the fish farm cage clusters.

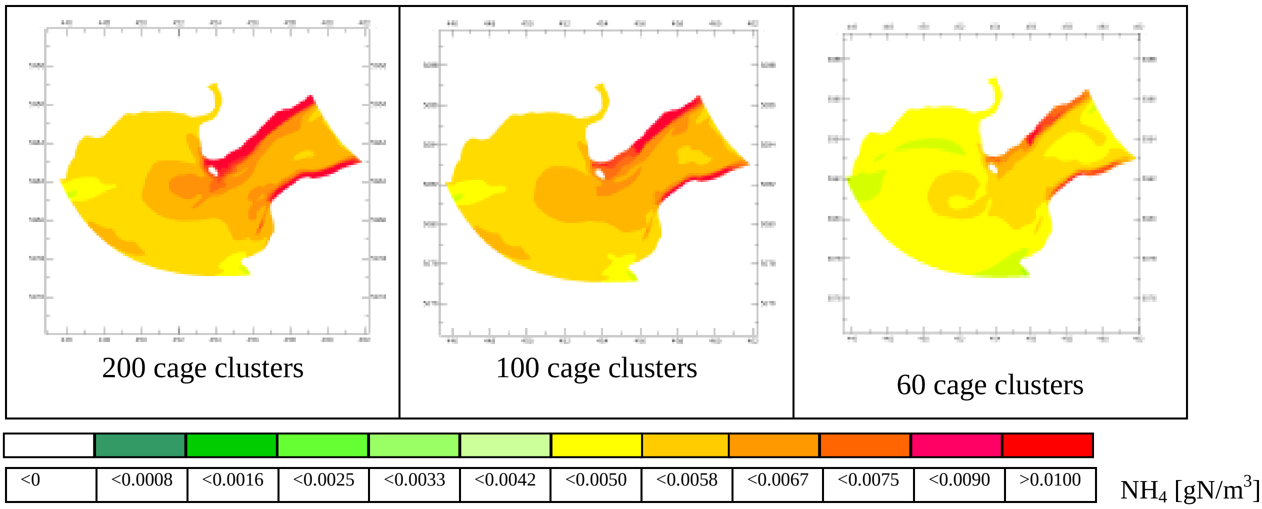


Figure 8. Determination of the site-specific holding capacity: Dissolved ammonium distribution for various number of fish farm cage clusters

Excessive ammonium levels resulted for a scenario of 200 cage clusters. For 100 cage clusters critical ammonium concentrations were observed in the North and South strips close to the shoreline, whereas in the channel the 50% limit was not exceeded. A minor impact on ammonium levels in the area resulted in a scenario with 60 cage clusters. Fish mass stored in 60 cage clusters corresponds to 400 tons of tiger grouper.

4. Discussion

The model approach adopted appears to be sufficient for the short term simulation of ammonium distribution in the region. However, significant negative and positive discrepancies between model results and field data in the nutrient distribution indicate that localized and additional sink and source processes other than the considered fish farm effluents must be taken into account in future efforts to improve the numerical water quality model. In this context, water-sediment interactions in the shallow study area, such as ammonium release from the sediment and phosphate adsorption to iron hydroxides, exchange processes which are impacted by erosion and bioturbation, seem to be of major relevance and should be included in a local parametrisation. Another major process not addressed in the model is the horizontal transfer of matter between the sea and the numerous mangrove belts, which temporarily function as a sink or a source for dissolved inorganic nutrients (Dham et al., 2002).

Furthermore, in the present study it was assumed that the uptake of nutrients by the phytoplankton and phytobenthos is largely compensated by remineralisation and can thus be neglected in the modelling. However, these processes exhibit a pronounced spatial and temporal heterogeneity, generally depending on light availability and hence on water depth as well as on the local supply of organic matter. In further studies, the assumption of a zero balance of autotrophic and heterotrophic processes should be tested with adequate field measurements.

It should be noted that in this study the holding capacity determination is only based on the level of the background concentrations; no spatial factor is addressed. In practice the environmental quality standards (EQS) that constitute the holding capacity of a specific site are defined for a zone where the receiving water body and bed-sediment are changed from their normal (background) state. This area (or volume) where EQS can be exceeded by a factor is called as *allowable zone of effects* (AZE) (SEPA, 2004). AZE determination also depends on the type of environmental impact. In cases where the impact is primarily benthic this zone is defined according to the extend of sedimentation of faecal and food pallets (Ervik et. al., 1997). On the other hand, when the primary impact is on the receiving water body, flushing time calculation can be useful. According to SEPA (2005) if the flushing time is smaller than 3 days or the total biomass in the system is less than 500 t, this impact can be disregarded. The AZE for fish farming activities is set to be 100 m in Scottish practice when the EQS in the water column are concerned (SEPA, 2006). It can be stated that despite strong tidal currents, calculation of the flushing time to decide on the extend of impacts can lead to more insight to the problem.

5. Acknowledgements

The present study was carried out as part of the SPICE project “Science for the Protection of Indonesian Coastal Environments” funded by the German Ministry of Education and Research (grant number 03F0393A) and the Indonesian Ministry of Fisheries from 2004 to 2007. Responsibility of the content is with the authors.

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7. Nutzen und Verwertbarkeit des Ergebnisses

Die im Laufe des Vorhabens gewonnenen Beobachtungs- und Modelldaten stellen bereits für sich allein genommen eine wichtige Datenbasis für die noch wenig charakterisierten indonesischen Küstengewässer dar, auf die weitere Projekte sowohl mit grundlagen-orientierten Forschungsarbeiten als auch mit angewandten Fragestellungen im Bereich des marinen Umwelt- und Naturschutzes sowie im Küstenzonenmanagement aufbauen können.
Konkret steht mit dem aus der Entwicklung des DSS resultierenden Empfehlungen eine wissenschaftlich begründete Leitlinie für indonesische Regierungsbehörden und die Marikulturwirtschaft zur Verfügung, die eine umweltgerechte Erweiterung und Raumplanung zukünftiger Fischzuchtaktivitäten ermöglicht. So bestehen bereits fortgeschrittene Planungen der indonesischen Fischereibehörden, im Bereich der Seribu-Inseln erste Pilotanlagen zum Sea-Ranching zu etablieren, zu denen die entwickelten hydrodynamischen Modelle wichtige Datengrundlagen liefern 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 das Bewusstsein für die Notwendigkeit einer nachhaltigen Weiterentwicklung des ausgedehnten indonesischen Küstenraums stärkt. Nicht unerwähnt bleiben soll auch, dass die Teilnehmer beider Seiten in dem Projekt viel von den kulturellen und wirtschaftlichen Eigenarten des Partnerlandes gelernt und mit auf den Heimweg genommen haben, sicherlich ist dies eine gute Basis für zukünftige bilaterale Kooperationen und Entwicklungen. Die Etablierung eines Double-Degree Master of Science in Coastal Geosciences and Engineering zusammen mit dem Technological Institute Bandung (ITB) ist bereits weit fortgeschritten, was ohne die im Laufe des Vorhabens entstandenen Kontakte nicht denkbar wäre. Zur logistisch-technischen Unterstützung wurde dem ITB durch den Forschungsdezernenten der Universität Kiel ein kleines Forschungsboot übergeben.

Aufgrund der im Rahmen des Projektes durchgeführten Trainingsaktivitäten wurde seitens des Gouverneurs Bupati Rahmadan und LIPI der Wunsch herangetragen, sich an der Entwicklung und Durchführung eines überregionalen marinen Trainingszentrums auf den Seribu-Inseln zu beteiligen. Das geplante Trainingscenter soll von einem Konsortium aus

ITB, IPB und der University of Indonesia in Jakarta getragen werden und in einem transdisziplinärem Ansatz abiotische, biologische und sozioökonomische Inhalte vermitteln. Die baulichen Voraussetzungen werden seitens der Provinz Seribu finanziert. Es fehlt allerdings an Ausbildungskapazität im Bereich moderner Meeresforschung sowie an Mitteln für die erforderliche Messtechnik, so dass von einer Beteiligung zunächst abgesehen wurde.

Die im Projekt gewonnenen Erkenntnisse haben gezeigt, dass weitere Parameter im Entscheidungsprozess des DSS anzusprechen sind. Sie bilden daher eine wichtige Basis für die Weiterentwicklung des Systems in einem breiteren Kontext, der auch die sozioökonomischen Aspekte berücksichtigt. Daher wurde ein Anschlussvorhaben formuliert, in dem die umweltrelevanten als auch sozioökonomische Entscheidungskriterien zusammengeführt werden, um eine in beiderlei Hinsicht ausgewogene Entwicklung der Marikultur in der indonesischen Küstenraumplanung zu gewährleisten.

8. Erfolgte oder geplante Publikationen

Schriften:

Hoppe, K. & Krost, P. (in prep): Influence of a fishfarm on the benthic community; a case study in a tidally influenced region in Riau region, Indonesia.

Krost, P. (in prep.): Sediments carrying capacity of organic pollution and cumulative effects by fish farming in a tidally influenced region in Riau region, Indonesia.

Krost, P. (in prep.): The geochemical response of sediments to organic loading from fish farming; a case study in a tidally influenced region in the Riau region, Indonesia.

Ladwig, N. & Hesse, K.-J. (in prep.): Evaluation of nutrient discharge and disposal from a coastal fish farm in Indonesia.

Landeta Reyes, F. (2005): Development of a wave model for a fish farm in archipelago Seribu, Indonesia. Master Thesis Coastal Research Laboratory, Universität Kiel: 86 S., Kiel

Maicher, D. (2005): Sedimentary characteristics of a shelf reef exposed to fish farm operations, Kepulauan Seribu, Indonesia. Master Thesis Coastal Research Laboratory, Universität Kiel: 105 S., Kiel

Mayerle, R., W. Windupranata & K.-J. Hesse (in press): A decision support system for the sustainable environmental management of marine fish farming. FAO Global Review of

Cage Aquaculture, 2nd International Symposium on Cage Aquaculture in Asia (CAA2), Hangzhou, P.R. China.

Özgürel, I. (in prep.): Numerical modeling of the holding capacity of coastal finfish mariculture in Indonesia.

Róisín Niederndorfer, K. (2006): Investigation on the dynamics of particulate matter emissions from Hiang Fischeries Fish Farm Pulau Serai, Indonesia. Master Thesis Coastal Research Laboratory, Universität Kiel: 189 S., Kiel

Van der Wulp, S. (2006): Nutrient mass balance modelling of cage fish farms – Case study Pulau Serai, Indonesia, Master Thesis Coastal Research Laboratory, Universität Kiel: 118 S., Kiel

Van der Wulp, S. (in prep.): Mass balance modelling for determination of nutrient emissions from floating cage fish farms in Indonesia.

Windupranata, W. (2007): Development of a Decision Support System for Suitability Assessment of Mariculture Site Selection. Dissertation, Universität Kiel, 125 pp.

Vorträge:

Hesse, K.-J. and N. Ladwig (2005): Environmental impacts of marine fish farming: Development of a decision support system. Vortrag Workshop Marine Surveying, Seribu, Jakarta, 13.04.2005.

Mayerle, R. (2005): Sustainable management of coastal living resources. Vortragsreihe National University Cheng Kung, Tainan, Taiwan, National Taiwan Ocean University, Keelung, National Sun Yat-sen University, Kaohsiung, 7.-11-03.2005.

Mayerle, R., W. Windupranata and K.-J. Hesse (2006): A decision support system for the sustainable environmental management of marine fish farms. Vortrag, 2nd International Symposium on Cage Aquaculture in Asia (CAA2), 3.-8. Juli 2006, Hangzhou, P.R. China.

Mayerle, W. Windupranata, K.-J. Hesse, K.-H. Runte, I. Jaya and F. Feliatra (2006): Development of a decision support system for the sustainable management of coastal living resources. Vortrag und Abstract SLAS Conference Southeast Asia Coastal Governance and Management Forum: Science meets Policy for Coastal Management and Capacity Building, Bali, 14.-16.11.2006.

B. ERFOLGSKONTROLLBERICHT

1. Beitrag des Ergebnisses zu den förderpolitischen Zielen des Förderprogramms

Das Vorhaben ist dem Cluster „Coastal Ecosystem Health“ des SPICE Projektverbundes (Science for the Protection of Indonesian Coastal marine Ecosystems) zugeordnet, welcher einen wesentlichen Bestandteil der WTZ der Bundesregierung in Meeres- und Geowissenschaften mit Indonesien darstellt. Neben den allgemeinen Zielsetzungen der WTZ, die u.a. eine Verbesserung der bilateralen Beziehungen, den Aufbau von wissenschaftlichen Netzwerken, die Erschließung neuer Forschungsregionen sowie den Ausbau von Forschungskapazität im Partnerland zum Inhalt haben, zielen die im SPICE-Verbund durchgeführten Aktivitäten darauf ab, unser wissenschaftliches Verständnis der Prozesse in tropischen Land/Meer-Übergangsbereichen zu erweitern und einen anwendungsnahen Beitrag für ein verbessertes nachhaltiges Umwelt- und Ressourcenmanagement der indonesischen Küstengewässer zu leisten. Sie liefern somit einen wichtigen Input zu dem internationalen IGBP-Programm LOICZ (Land Ocean Interaction in the Coastal Zone). Die im vorliegenden Projekt durchgeführten Forschungs- und Entwicklungsarbeiten stehen im Einklang mit den im Aktionsplan der bilateralen Kooperation formulierten Zielen. Die in dem Vorhaben gewonnenen Erkenntnisse und Produkte tragen dazu bei, die indonesischen Küstengewässer und ihre Lebendressourcen besser zu verstehen, zu schützen und zu nutzen. Das DSS als Endprodukt liefert eine Entscheidungsgrundlage für die nachhaltige Ressourcennutzung der indonesischen Küstenmeere, auf die Regierungsstellen und Fachbehörden, die in Entscheidungsprozesse des Küstenzonenmanagements sowie des Aufbaus und der Lizenzierung von Fischzuchtaktivitäten einbezogen sind, zurückgreifen können.

Die im Vorhaben integrierten Schulungs-, Trainingseinheiten und Workshops in Indonesien leisteten einen Beitrag zur Verbesserung der Forschungskapazität im Partnerland. Einen weiteren Schwerpunkt bildete die Aus- und Fortbildung indonesischer und deutscher Studenten. Aus dem Projekt resultierten 4 Masterarbeiten, die im Rahmen des Master-Studienganges „Coastal Geosciences and Engineering“ der Universität Kiel durchgeführt wurden. Flankiert wurde das Projekt weiterhin durch ein BMBF-gefördertes Stipendiumprogramm des Deutschen Akademischen Austauschdienstes (DAAD). Zwei indonesische DAAD-Stipendiaten waren im Rahmen des Postgraduiertenprogramms „Coastal Geosciences and Engineering“ mit Spezialfragestellungen in dem Vorhaben eingebunden.

2. Wissenschaftlicher Erfolg des Vorhabens

Als Ergebnis des Vorhabens liegt ein modellgestütztes Entscheidungsfindungssystem vor, welches eine umweltgerechte Auswahl geeigneter Küstengebiete für die künftige Etablierung von Fischzuchtanlagen als auch eine Bestimmung der verträglichen Ausbaugröße der Farmen ermöglicht. Die hierfür gewählte Forschungsstrategie bestand aus einer Kombination von Naturmessungen, numerischen Modellierungen und GIS-Anwendungen. Die konzeptionelle DSS-Strategie ist auf andere Küstengebiete übertragbar. Das gleiche gilt für einzelne Module des Vorhabens, wie das Modell zur Bilanzierung der Nährstoffemissionen aus den Käfigfarmen.

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 beiden Untersuchungsgebiete in den Seribu Inseln und im Riau Archipelago (Bintan) vor. Sowohl das Ökosystem des Seribu-Archipels als auch dasjenige der Küstengebiete um Bintan gelten als gefährdet. Hauptursache sind zum einen die anthropogenen Belastungen durch den expandierenden Großraum Jakarta, zum anderen der intensive Bauxitabbau im östlichen Riau Archipel. Die im Zuge der 4 Messkampagnen gewonnenen feldorientierten Datensätze und Modellergebnisse bilden somit auch eine Grundlage für weiterführende Projekte, die eine ökologische Zustandsbeschreibung dieser bedrohten Systeme anstreben.

Ein Erfolg des Vorhabens liegt auch in der erreichten Ausbildungseffizienz: Aus dem Projekt resultierten insgesamt fünf Examensarbeiten. Die im Laufe des Vorhabens entstandenen Kontakte reichen weit über die ursprünglich beteiligten Partnereinrichtungen Institut Pertanian Bogor (IPB) und der Universität Riau (UNRI) in Pekanbaru hinaus. Zusammen mit dem Gondol Research Institute for Mariculture (Bali) und dem Institute of Technology in Bandung (ITB) wurde ein weiterführendes Kooperationsprojekt vorbereitet. Die Gespräche mit dem ITB mündeten in konkrete Planungen zur Etablierung eines Double Degree-Studienganges in Coastal Geosciences and Engineering zusammen mit der Universität Kiel.

3. Einhaltung des Finanzierungs- und Zeitplanes

Der Zeit- als auch der Finanzierungsplan konnten im wesentlichen wie vorgesehen eingehalten werden. Geringfügige Verschiebungen in den einzelnen Positionen im Rahmen der wechselseitigen 20%-Deckung hatten keine Änderung des Gesamtbedarfs zur Folge. Sämtliche Messkampagnen konnten antragsgemäß durchgeführt werden. Infolge der umständlichen Prozeduren bei der temporären Einführung der Geräteausstattung und der Einholung der Forschungsgenehmigungen verzögerte sich die Terminierung der ersten und der letzten Messkampagne um einige Wochen.

4. Verwertbarkeit der Ergebnisse

Zur Verwertbarkeit der Ergebnisse sei auf §7 des Schlussberichtes verwiesen. Mit dem aus der Entwicklung des DSS resultierenden Empfehlungen wird eine wissenschaftlich begründete Leitlinie für indonesische Regierungsbehörden und die Marikulturwirtschaft geschaffen, die im Rahmen des Küstenzonenmanagements eine umweltgerechte Erweiterung und Raumplanung zukünftiger Fischzuchtaktivitäten ermöglicht. Es besteht auf indonesischer Seite ein starkes Interesse an einer Erweiterung des DSS um sozioökonomische Aspekte und einer großflächigen Anwendung auf den indonesischen Küstenraum.

5. Erfindungen und Schutzrechtsanmeldungen

Entfällt

6. Ungelöste Fragen

Die ungelösten Fragen betreffen weniger geplante Aufgabenstellungen, die nicht bewältigt werden konnten, als Forschungsdefizite, die sich während der Laufzeit des Projektes erst ergaben. Kenntnislücken betreffen u.a. die quantitative Formulierung des Zusammenhangs zwischen partikulären Emissionen aus den Fischzuchtanlagen und der Sedimentqualität. Infolge der geringen Sinkgeschwindigkeiten, des kohesiven Charakters sowie der ständigen Remobilisierung und Transformation des deponierten partikulären Materials sind kritische Belastungsgrenzen partikulärer organischer Emissionen nur schwer zu definieren. Hinzu kommt, dass quantitative Informationen über die komplexen Wechselwirkungen zwischen

Sediment und Wasserkörper sowie über Umsetzungsraten der organischen Substanz als auch der (gelösten) Nährstoffe in den Untersuchungsgebieten fehlen. Als pragmatischer Grenzwert der tolerierbaren Sedimentbelastung wurde daher eine kritischen Schubspannung definiert, bei der das sedimentierte Material aus dem Bereich der Fischfarmen hinaus weiterverfrachtet wird. Die numerische Modellierung der Wasserqualität beschränkte sich zunächst auf den Leitstoff Ammonium. Da stets eine gute Sauerstoffversorgung vorhanden war und davon ausgegangen wurde, dass sich in den oligotrophen tropischen Küstengewässern die Raten der Nährstoffremineralisation und der Nährstoffaufnahme die Waage halten, wurde Nitrifizierung als einziger Transformationsprozess in der Modellierung berücksichtigt. Unberücksichtigt blieb bisher jedoch der oben bereits genannte Nährstoffaustausch mit dem Sediment.

Das im vorliegenden Projekt konzipierte DSS bietet eine Entscheidungshilfe für die ökologisch nachhaltige Ansiedlung von Fischfarmanlagen. Gleichermaßen bedeutend für den Entscheidungsprozess sind jedoch neben den umweltrelevanten Aspekten sozioökonomische Entscheidungskriterien. Nur unter Berücksichtigung beider Erfordernisse ist eine ausgewogene Entwicklung der Marikultur in der indonesischen Küstenraumplanung zu gewährleisten. Es soll daher der Aufgabe einer Projektanschlussphase überlassen sein, in einem umfassenden DSS sowohl die umweltbezogenen als auch die sozioökonomischen Aspekte zusammen zu führen.

C. ZUSAMMENFASSUNG

In den Küsten- und Inselregionen Indonesiens sind Belastungen der Meeresumwelt durch eine zunehmende Intensivierung der marinen Aquakultur ein Problem von großer wirtschaftlicher Tragweite. Ziel des BMBF-Projektes war daher die Entwicklung eines Decision Support Systems (DSS) für ein ökologisch nachhaltiges Management küstennaher Fischzuchtanlagen.

Das DSS basiert auf einer Kombination von GIS-Technologien, numerischen Simulationsmodellen und Naturmessungen. Mithilfe des Systems können potenzielle Eignungsgebiete für die Ansiedlung von Netzkäfigfarmen anhand gewichteter Umweltkriterien identifiziert und die zulässige Größe und Produktionskapazität der Zuchtanlagen auf Basis von Modellsimulationen bestimmt werden. Es besteht aus 3 Stufen: In einem ersten Schritt erfolgt großskalig eine Vorauswahl von potenziell geeigneten Küstengewässer anhand von chemischen und physikalischen Schlüsselkriterien, von Sedimentcharakteristika und Nutzungsarten. In einem zweiten Schritt erfolgt eine lokale Auswahl von Eignungsgebieten auf Basis der Wassertiefen, der Strömungsgeschwindigkeit, der Wellenexposition, der Bodenneigung und der Bodenschubspannung. In einem letzten Schritt wird die maximal tolerierbare Besatzgröße anhand von Simulationsrechnungen der Nährstoffimissionen bestimmt, die einen festgelegten Grenzwert nicht überschreiten dürfen.

Die Funktionalität des DSS wurde in zwei Küstengebieten Indonesiens getestet. Die Ergebnisse bestätigen die Eignung des Systems als Entscheidungshilfe für Regierungsbehörden und Marikulturwirtschaft auf dem Wege zu einer umweltgerechten Erweiterung und Raumplanung zukünftiger Fischzuchtaktivitäten.