Options and Tradeoffs in Krabi's Coastal Land Use

Tipparat Pongthanapanich

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Tipparat Pongthanapanich
Department of Environmental and Business Economics
University of Southern Denmark
Niels Bohrs Vej 9-10
DK-6700 Esbjerg
Tel.: +45 6550 4151
Fax: +45 6550 1091
E-mail: tpo@sam.sdu.dk

Abstract

This paper explores the tradeoff options for optimal coastal land use in Krabi's coastal land development zone (CLDZ). Maximizing the net private benefit and maximizing the net environmental benefits, subject to the constraints set by land availability, effluent discharge from shrimp farms, and rice consumption are optimized via multiobjective programming. It is found that although the benefit from present land use pattern is close to the efficient level (Pareto frontier), reallocation of land use and revision of CLDZ are required in order to achieve an efficient outcome of planning. Designating aquaculture zones on the basis of carrying capacity is found to be an important scheme to control the impacts of shrimp farm discharges. The combined measures of carrying capacity and green taxation would lead to economically and environmentally responsible aquaculture. Compliance with aquaculture effluent standard alone could potentially lead to the detrimental optimum, and would be superfluous if aquaculture zones based on carrying capacity were designated.

Keywords: coastal management, Pareto frontier, multiobjective programming, Krabi

JEL classification: C61, D62, D74, Q24

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1. Introduction

Competing land use generates resource use conflict along the coastline. Mangrove conservation *vis-à-vis* shrimp production is a widely recognized conflict in tropical countries. This issue is undoubtedly relevant to Thailand as the world largest of cultured shrimp export. The conflict relates to the inherent complexity of coastal system which needs to be well understood and treated in decision-making. Additionally, the unawareness of externalities and nonmarket values would lead to overexploitation and thus degradation of natural-environment (see Pearce and Turner, 1990; Tietenberg, 1992; and Tisdell, 1993). Taking into account the environmental costs and benefits is required in the environmental planning that aims at efficient outcome (see Heal, 2000; and Millennium Ecosystem Assessment, 2005).

The efficient or optimal use of coastal land use (CLU) was examined in literature. For instance, Bell and Cruz-Trinidad (1996), Cruz-Trinidad et al. (1996) and Kantangkul (2000) determined the optimal use of mangrove areas. Maximum net social benefit (NSB) where both private benefit and environmental values are accounted given some technical and environmental constraints was optimized by using a single-criterion approach, i.e. linear programming (LP). However, CLU planning usually involves with the tradeoffs among alternative use patterns/options. This is obviously a multicriteria decision problem in nature. Despite this fact, Pongthanapanich (2003) revealed that examination of CLU problem is often limited in the single-criterion framework.

This paper thus aims to determine the optimal use of coastal land in multicriteria framework. The Pareto-efficiency frontier is derived and the tradeoffs among optimal coastal land use (OCLU) options along the frontier are then examined. The Pareto frontier contains an efficient set of feasible solutions, which can be approximated from multiobjective programming method, see Cohon (1978) and Yu (1985). The recent application of the method to coastal resource found in Leung et al. (2001) who considered simultaneously the maximizing of economic rent, employment and income objective derived from fishery resource utilization in the Barents Sea. Here the maximize net private benefit (NPB) and maximize net environmental benefit (NEB) objectives are optimized at once. NPB comprises the private gains from land use activities (decision variables) while NEB elicits the implicit economic values of corresponding environmental attributes generated from the land use. Land availability, rice consumption and carrying capacity of the receiving waters for shrimp farm discharges are set as technical constraints.

Various scenarios, Sx, of the management of shrimp farming externalities are explored: S1) considering the carrying capacity of receiving waters for the effluent, S2) enforcing the effluent standard, S3) combined S1 and S2, and S4) adopting the green (corrective) tax regime together with carrying capacity. The coastal land development zone (CLDZ) in Krabi, the Andaman coast of Thailand, is the case study. The approximated Pareto frontiers obtained provide insight of land use tradeoffs, and bring to some conclusion on the effectiveness of coastal planning designs.

The next section provides an overview of CLU in Karbi's CLDZ. The methodology as well as the solving technique is subsequently described. Then, the empirical model is presented where the decision variables (i.e. land use activities), objective functions, coefficients and parameters are elaborated. The results of four scenarios and sensitivity analysis are presented next, and followed by discussion and conclusion.

2. Coastal Land Use in Krabi's CLDZ

The CLDZ was proposed by Land Development Department (LDD) as a guideline for Thailand's coastal land management plan at provincial level.[1] It is

1 "Coastal zone" is bounded by the edge of watershed and continental shelf which covers a broader area than CLDZ. By this definition, coastal zone consists of two parts, i.e. land and sea. The coastal land is divided in two areas: 1) the *Inner Influenced Zone* (IIZ) that is strongly influenced by the sea, and 2) the *outer influenced zone* that covers the outer area of IIZ up to

classified into 14 zones (Table 1) on the basis of most appropriated land utilization type obtained from prioritizing numbers of physical suitability maps. Subdistrict boundary is used to demarcate the zone as to support the administrative procedure and development at community level. Consequently, 25 provinces (142 districts; 837 subdistricts) both on the Gulf of Thailand and the Andaman coastline are proclaimed as CLDZ. It covers 21.5 million rai (6.25 rai=1 hectare; 0.16 hectare=1 rai) or 6.5% of the entire kingdom's area. Krabi's CLDZ covers around 1.3 million rai in 5 districts (28 subdistricts) or 44% of total provincial area.

Table 1. Classification of Coastal Land Development Zone (CLDZ)

Classification and conditions of uses	Areas 2/		
	Thailand	Krabi	
	(rai)	(rai)	(%)
A. Agricultural zone: Physically suitable for agriculture, e.g. qualified soil properties and topography	11,134,428	512,646	39.7
A1. Paddy zone	4,930,211	74,234	5.8
A2. Orchard zone	1,883,501	319,008	24.7
A3. Para rubber and oil palm zone	1,307,166	59,421	4.6
A4. Coconut zone	1,314,976	9,810	0.8
A5. Horticulture zone	401,395	-	-
A6. Pasture zone	253,355	-	-
A7. Aquaculture zone	1,043,824	50,173	3.9
B. Forest zone: Classified under forest laws which respect to utilization schemes 1/	5,893,263	449,696	34.9
B1. Conservation forest zone: Declared as preservation zone, national park, wildlife preserve, wildlife sanctuary and mangrove conservation zone	2,335,435	36,214	2.8
B2. Economic forest zone: Comprises inland forest and mangrove economic zone A	2,879,198	403,370	31.3
B3. Mangrove economic zone B	678,630	10,112	0.8
C. Urban zone: Mainly comprises industrial area and residential area.	1,188,236	16,560	1.3
D. Military area	26,041	-	-
E. Conservation area: Conserved for specific interests such as mud flat, wetland, rehabilitation of mangrove	116,254	-	-
F. Swamp: Tidal flood low land that becomes natural ponds and reservoirs	85,337	-	-
G. Beaches: Suitable for tourism and recreation	108,261	9,236	0.7

the watershed which is influenced by fresh water. CLDZ by LDD's definition covers every single subdistrict that takes part of IIZ.

H. Mud Flat: Important nursery ground and suitable for shellfish culture, e.g. oyster, cockle, mussel, or for conservation	1,732	-	-
I. Islands	663,752	21,898	1.7
J. Mountains	847,386	201,633	15.6
K. Abandoned mining area: Can be recovered for other uses, e.g., growing of high-growth trees, reservoirs, places to bury garbage	127,026	5,265	0.4
L. Salt pan	56,325	-	-
M. Peat: Tidal-flood and bio-diversity importance area	183,498	-	-
N. Water body: Rivers and estuaries	1,080,461	73,051	5.7
Total Area	21,512,000	1,289,985	100.0

Note: 1/ Under the cabinet resolution 15 December 1987, mangroves are classified into 2 main zones, i.e. conservative zone and economic zone. The former covers 20 meters of riverside along the estuaries and 75 meters of coastline edges. The latter is divided into 2 sub-zones: economic zone A—allowed for wood concession, and economic zone B—allowed for other economic uses, e.g. agriculture, aquaculture, mining, housing.

2/ 6.25 rai = 1 hectare (ha); 0.16 rai=1 ha.

Source: Office of Coastal Land Development, Land Development Department (LDD).

The analysis centers on the land use conflict zones in CLDZ. These are aquaculture/shrimp zone (AQZ), mangrove economic zone B (MBZ), paddy zone (PDZ) and para rubber & oil palm zone (ROZ). The present activities in these zones conflict in land use: Various types of land use exist in each zone, although a specific land utilization type is claimed for a particular use under CLDZ (Table 2). In AQZ, For instance, around 36% (18,140 rai) is utilized for rubber plantation and 13% (6,439 rai) is mangrove while this zone is classified as suitable only for aquaculture. Only 10% (5,080 rai) is used in corresponding to its suitability that is for shrimp farming. On the other hand, in MBZ, around half of the area is left as stand mangrove while the less of the area is utilized mostly for rubber plantation and shrimp farms. In both PDZ and ROZ, rubber and oil palm plantations are found dominantly. However, other types of uses exist in these zones.

Table 2. Number of area of existing land use in selected Krabi's CLDZ

Types of existing land use	AQZ (A)	MBZ (M)	PDZ (P)	ROZ (R)	Sum
Abandoned paddy (apd)	1,907	268	2,254	175	4,604
Mangrove forest (mgv)	6,439	4,650	268	487	11,844
Oil palm (oil)	6,991	476	8,064	12,633	28,164
Para rubber (rub)	18,140	1,860	50,420	38,685	109,105
Shrimp farm (srp)	5,080	1,008	314	782	7,184
Transplanted paddy field (tpd)	5,704	60	5,665	521	11,950
Others (i.e. other types of forest, mixed orchards, villages, grass, scrub)	5,912	1,790	7,249	6,138	21,089
Sum	50,173	10,112	74,234	59,421	193,940

Note: 1) AQZ is aquaculture zone; MBZ is mangrove economic zone B; PDZ is paddy zone; and ROZ is rubber and oil palm zone (unit in rai).

2) The error of map overlaying is around 1.1% of total CLDZ area.

Source: Analyze from CLDZ and existing land use spatial data (map scale 1:50,000). The data was prepared in 1999 by the Office of Coastal Land Development, LDD.

The potential land use activities in each zone as decision variables are defined corresponding to the existing land use (ELU) and the CLDZ framework. This is elaborated later in Empirical Model.

3. Methodology

The concept of multiobjective programming is provided. Subsequently, the solving technique used for the approximation of solution set is described.

3.1. The Conceptual Model

The main idea of multiobjective programming is to establish an efficient set of feasible solutions from multiple criteria (objectives) problem. The efficient set of objective values, denoted as $\underline{Eff}\ \underline{Z}\ (\underline{x})$ where $\underline{x}$ is the solution set of decision variables, represents Pareto optimal solutions where improving a solution cannot be made by not worsening the other(s). In other words, the solution set is efficient with respect to Pareto preference if and only if there is no other feasible solution that at least is as good as $\underline{Eff}\ \underline{Z}\ (\underline{x})$ with respect to all objectives. The entire efficient set, so-called Pareto-efficiency frontier, thus contains the feasible and nondominated/noninferior solutions.[2] Additionally, satisfying Pareto optimality implies that the efficient solutions can be obtained by solving mathematical programming. See Yu (1985) for the mathematical details of Theorems, Definitions and Properties.

For two objectives problem as relevant to this paper, the conceptual model can be presented as follows:

$\underline{Eff}\ \underline{Z}\ (\underline{x}) = [Z_1(\underline{x}), Z_2(\underline{x})]$

subject to $\underline{x} \in \underline{F}$

where $Z_1(\underline{x})$ and $Z_2(\underline{x})$ is the respective objective function 1 and 2, and $\underline{F}$ is the set of feasible solutions.

The mathematical programming can then be formulated as follows:

Maximize $Z_1(\underline{x}) = \sum_{j=1}^{n} c_{j1} X_j$

Maximize $Z_2(\underline{x}) = \sum_{j=1}^{n} c_{j2} X_j$

subject to $\sum_{j=1}^{n} a_{ij} X_j \{\leq,=,\geq\} b_i$ $\qquad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n$

and $\qquad X_j \geq 0$

where X_j = decision variable j

2 The terms "efficient" solution, "Pareto optimum", "nondominated" or "noninferior" solution are, thus, used interchangeably in literature.

c_{j1} = coefficient of each X_j in objective 1
c_{j2} = coefficient of each X_j in objective 2
a_{ij} = technological coefficient of each X_j in constraint i
b_i = right-hand-side (RHS) constant of each constraint i
n = number of decision variables
m = number of constraints

The above formation is the modification of standard LP that would arrive at a static optimum. Meanwhile, the underlining assumptions of LP (i.e. proportionality, additivity, divisibility, nonnegativity and deterministic) also hold. See more details in Pongthanapanich (2003).

3.2. *Solving Techniques*

Multiobjective programming model can be solved by using some alternative techniques such as the constraint method (parametric RHS), the weighting method (parametric weights), simplex algorithm. The review of the methods has been provided by Pongthanapanich (2003). See Cohon (1978), Dykstra (1984), or Romero and Rehman (2003) for the mathematical details.

In this paper, the noninferior set estimation, NISE (Cohon, 1978 and Cohon et al., 1979) is employed. The merits of this method are discussed later. The recent application of NISE is found in El-Gayar and Leung (2001). The technique is derived from the weighting method by employing a weighted objective function as shown below:

Maximize $w_1Z_1(\underline{x})+w_2Z_2(\underline{x})$
subject to $\underline{x} \in \underline{F}$
and $\underline{w} \geq 0$

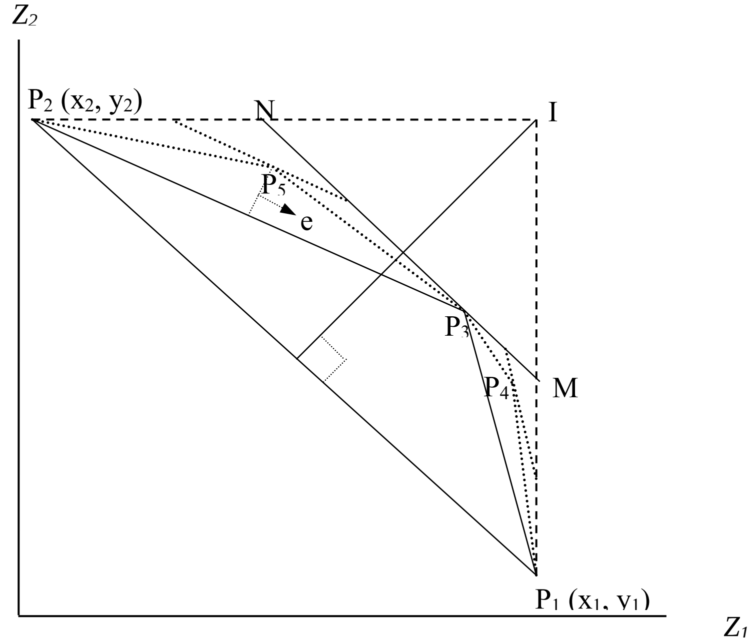
Instead of using arbitrary weights, NISE employs the information of the ideal (utopia) and anti-ideal (nadir) solution to generate an initial weight for further approximation of the efficient set. The ideal and anti-idea solution for two objectives problem can simply be obtained from optimizing each of the objectives separately, see Ehrgott and Tenfelde-Podehl (2003). In Figure 1, $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ are the results of both extreme values all of which defines the range of efficient set in objective space. With the assumed convexity of feasible region in objectives space, this technique guarantees that there is no efficient solution below the segment P_1P_2. Thereby, a zone where the efficient set located can be defined, i.e. IP_1P_2. Point I is the ideal where the optimal values of both objectives are achieved. Use P_1 and P_2 as starting points for the calculation of initial weight which equals the slope of P_1P_2:

$$-\frac{w_1}{w_2} = \frac{y_2 - y_1}{x_1 - x_2} = a$$

Set w_2 equal to one, hence w_1 is equivalent to a. The weighted objective function is then modified as became maximize $aZ_1(\underline{x})+Z_2(\underline{x})$. The model can then be solved in the same way as a standard LP for the corresponding noninferior/efficient solution in the objectives space, i.e. P_3. Here the General Algebraic Modeling System, GAMS (Brooke et al., 2003), is used for the LP-runs. Meanwhile, the area of the noninferiority zone is reduced (from IP_1P_2 to MP_1P_3 and NP_2P_3). In further iterations, P_1 and P_3 as well as P_2 and P_3 are used as reference points. Other noninferior solutions, P_4 and P_5, are found respectively within the remaining area of the zone by using the same technique as depicted.

The next iteration is operated on and on. The termination of the algorithm is corresponded with the maximum allowable error ("e" in Figure 1) of the approximation, which can be controlled. This advantage cannot be achieved by using the simplex algorithm. Moreover, NISE can insure the entire/exact noninferior set, when the notion of the maximum allowable error is dropped (i.e. zero error). That is the line segment between the two reference points will be noninferior, if the optimal solutions obtained from further iteration are not changed from the previous iteration. Thereby, the solution set can be achieved with less effort by using NISE than the weighting method or the constraint method. The last two methods may not even fully cover the entire efficient set, while NISE can (Cohon et al., 1979).

Figure 1. Noninferior Set Estimation Method (NISE) with two maximizing objectives



4. The Empirical Model

This section provides the formulation of multiobjective programming of CLU problem. The decision variables, objective functions and their coefficients, and constraints as well as the parameters are described. The coefficients and the constraint set are defined differently in various model scenarios. The mathematical model is presented in the last sub-section.

4.1. Decision Variables

The decision variables are the potential land use activities suggested for each ELU in the selected CLDZ (Table 3). It should be noted that the mangrove areas in conservation zone and economic zone A under the cabinet resolution

15 December 1987 (see Note 1, Table 1) are not included in the analysis. Wood concession, the only economic activity allowed in zone A, has been completely terminated since 2001 throughout Thailand. Subsequently, the resolution 22 August 2002 was proclaimed—namely no other uses are permitted neither in zone A nor zone B except for conservation purposes. However, the analysis includes zone B (i.e. MBZ, see Table 2) in order to investigate whether this zone should be kept (22 August 2002) or used economically as used to be permitted (15 December 1987).

Also note that the abandoned paddy fields (apd) found in coastal area is mainly caused by insufficient supply of fresh water. In addition, the productivity is usually low as compared to that from the inland. Therefore, paddy production (tpd) is not introduced as a competing activity in non-existing paddy area, but rather in the existing area.

Table 3. Potential competing land use in Krabi's CLDZ classified by existing land use in each zone

CLDZ[1/]_Existing land use (Xx)	Land constraint -row no. (i)	Competing activities X_j [2/]					
		Mgv.refo. (mgr)[3/]	Mangrove (mgv)	Oil palm (oil)	Rubber (rub)	Shrimp (srp)	Paddy (tpd)
AQZ_apd (Aa)	1			/ [1]	/ [2]	/ [3]	
AQZ_mgv (Am)	2		/ [4]			/ [5]	
AQZ_oil (Ao)	3			/ [6]		/ [7]	
AQZ_rub (Ar)	4				/ [8]	/ [9]	
AQZ_srp (As)	5					/ [10]	
AQZ_tpd (At)	6					/ [11]	/ [12]
MBZ_apd (Ma)	7	/ [13]		/ [14]	/ [15]	/ [16]	
MBZ_mgv (Mm)	8		/ [17]	/ [18]	/ [19]	/ [20]	
MBZ_oil (Mo)	9	/ [21]		/ [22]		/ [23]	
MBZ_rub (Mr)	10	/ [24]			/ [25]	/ [26]	
MBZ_srp (Ms)	11	/ [27]				/ [28]	
MBZ_tpd (Mt)	12	/ [29]		/ [30]	/ [31]	/ [32]	/ [33]
PDZ_apd (Pa)	13			/ [34]	/ [35]	/ [36]	
PDZ_mgv (Pm)	14		/ [37]	/ [38]	/ [39]	/ [40]	
PDZ_oil (Po)	15			/ [41]			
PDZ_rub (Pr)	16				/ [42]		

PDZ_srp (Ps)	17				/ [43]	
PDZ_tpd (Pt)	18		/ [44]	/ [45]	/ [46]	/ [47]
ROZ_apd (Ra)	19		/ [48]	/ [49]	/ [50]	
ROZ_mgv (Rm)	20	/ [51]	/ [52]	/ [53]	/ [54]	
ROZ_oil (Ro)	21		/ [55]		/ [56]	
ROZ_rub (Rr)	22			/ [57]	/ [58]	
ROZ_srp (Rs)	23		/ [59]	/ [60]	/ [61]	
ROZ_tpd (Rt)	24		/ [62]	/ [63]	/ [64]	/ [65]

Note: 1/ AQZ is aquaculture zone; MBZ is mangrove economic zone B; PDZ is paddy zone; and ROZ is rubber and oil palm zone.

2/ For example, in row 1 (i=1) oil palm, para rubber and shrimp farming are the potential competing activities in Aa—namely aquaculture zone, AQZ, where the abandoned paddy, adp, exists; the subsequent abbreviation used for these three decision variables are oilAa, rubAa, and srpAa. The numbers in parentheses [j] denote the respective decision variables, X_j, where j=1,2,3,…,65.

3/ Mangrove reforestation under clear-cutting silviculture system of 10 years rotation period is also suggested as an alternative activity in mangrove zone (MBZ) where mangrove has been converted. This activity was encouraged under the cabinet resolution 30 July 1985.

Tourism is also recognized as an important source of income in Krabi province. However, the CLDZ proposed for recreation is classified in the beach and island zones (see Table 1). These zones are geographically suitable merely for tourism and other activities would not be economically better than tourism. In selected zones, tourism does not significantly compete in land use with other activities compare to those defined as decision variables. Thus, these two zones and land development for tourism in selected zones are not included in the analysis.

4.2. Objective Functions and Coefficients

Maximize NPB and NEB objective are optimized simultaneously. NPB denotes the overall net benefit that businesses including coastal dwellers as a whole would earn from utilizing the coastal land in various activities. The costs of land conversion/ preparation and land rent are considered. NEB exemplifies the overall net non-monetary benefit that society would gain from the natural-environment in connection to the land use option. Thus, the direct use value of mangrove (see Appendix 1) that coastal dwellers acquire is accounted in NPB. On the other hand, the indirect use value of mangrove and the external costs of shrimp farming (see Appendix 2) are accounted in NEB. However, when a green tax regime is imposed (see Model Scenarios), the externalities are then internalized. That is the costs are accounted via NPB objective. The coefficients (c_j), which represent the net benefits as described, are presented in Table 4.

Table 4. Net private benefit (NPB) and net environmental benefit (NEB) from each land use, c_j

Objectives/ Activities [1/]	c_j [2/]	Sources of data used to base the calculation
Maximize NPB		
mgvAm[4], mgvMm[17], mgvPm[37], mgvRm[51]	3,006	Direct use value of mangrove surveyed in Surat Thani province, Southern Thailand, in 1996 (see Appendix 1).
mgrMa[13]	3,207	Adjusted from Pongthanapanich (1995). The analysis is based on data from Royal Forest Department and assume 30 years project period (t) with 2 cycles of clear-cutting silviculture started in year 11.
mgrMo[21], mgrMr[24]	188	See mgrMa. Land development cost of 2,000 THB/rai and land rent of 1,000 THB/rai/year are also accounted.
mgrMt[29]	2,114	See mgrMa. Land development cost of 2,000 THB/rai and land rent of 300 THB/rai/year are also accounted.
mgrMs[27]	-6,085	Apply the same calculation as depicted above (mgrMa) except that reclamation cost is required (see Appendix 2).
oilAa[1], oilMa[14], oilPa[34], oilRa[48]	5,779	Based on Pongthanapanich (1995).
oilAo[6], oilMo[22], oilPo[41], oilRo[55]	3,027	See oilAa. Land rent of 1,000 THB/rai/year is also accounted.
oilMm[18], oilPm[38], oilRm[52]	5,511	See oilAa. Land development cost of 2,000 THB/rai is also accounted.
oilMt[30], oilPt[44], oilRt[62]	4,685	See oilAa. Land development cost of 2,000 THB/rai and land rent of 300 THB/rai/year are also accounted.
oilRs[59]	1,434	See oilAa. Remediation cost of shrimp pond soil is required (see Appendix 2).
rubAa[2], rumba[15], rubPa[35], rubRa[49]	3,346	Based on Pongthanapanich (1995).
rubAr[8], rubMr[25], rubPr[42], rubRr[57]	1,118	See rubAa. Land rent of 1,000 THB/rai/year is also accounted.
rubMm[19], rubPm[39], rubRm[53]	3,078	See rubAa. Land development cost of 2,000 THB/rai is also accounted.
rubMt[31], rubPt[45], rubRt[63]	2,337	See rubAa. Land development cost of 2,000 THB/rai and land rent of 300 THB/rai/year are also accounted.
rubRs[60]	74	See rubAa. Remediation cost of shrimp pond soil is required (see Appendix 2).
srpAa[3], srpMa[16], srpPa[36], srpRa[50]	99,462	Costs and yields (varied by prior land use types) of shrimp farming in Krabi is adjusted based on the survey data in 2000

		of intensive farming in Phang-nga province (Tokrisna, 2004). The average yields for Krabi are varied in the range of 1,123-1501 kg/rai/year (2 crops per year).
srpAm[5], srpMm[20], srpPm[40], srpRm[54]	49,285	See srpAa.
srpAo[7], srpMo[23], srpRo[56]	143,696	See srpAa.
srpAr[9], srpMr[26], srpRr[58]	76,730	See srpAa.
srpAs[10], srpMs[28], srpPs[43], srpRs[61]	95,884	See srpAa.
srpAt[11], srpMt[32], srpPt[46], srpRt[64]	98,822	See srpAa.
tpdAt[12], tpdMt[33], tpdPt[47], tpdRt[65]	204	Adjusted based on the data from OAE (2004).
Maximize NEB		
mgvAm, mgvMm, mgvPm, mgvRm	20,176	Indirect use value of mangrove (see Appendix 1).
mgrMa, mgrMo, mgrMr, mgrMt, mgrMs	10,088	Based on Pongthanapanich (1995), it can be estimated that the environmental value contributed by mangrove reforestation under clear-cutting silviculture system is around 50% of that by natural mangrove forest.
srpAm, srpMm, srpPm, srpRm	-29,880	Mangrove forgone benefits and the cost of abandoned shrimp farm are accounted (see Appendix 2).
srpMs	-6,697	Reclamation cost of abandoned farms is accounted (see Appendix 2).
srpAo, srpMo, srpRo, srpAr, srpMr, srpRr, srpPs, srpRs, srpAt, srpMt, srpPt, srpRt, srpAa, srpMa, srpPa, srpRa, srpAs	-1,603	Remediation cost of pond soil is accounted (see Appendix 2). The pond soil of the abandoned farms should be restored in the condition that is suitable for crops or plantations.

Note: 1/ Refer to Table 3 for the abbreviations of the decision variables. Unit in THB/rai/year.

2/ The average growth rate of producer price, 5% per year, is used for the calibration of the cost and benefit data.

4.3. Model Scenarios

Various model scenarios are set as to observe the consequences of different management mechanisms proposed to control the impacts of shrimp farming (Table 5). S1 considers the carrying capacity of the receiving waters for shrimp farming. This scenario assumes that the effluent is not treated before discharging. This is a common practice found in most developing countries including Thailand. The survey in 2000 revealed that only 6.5% of Thai shrimp farms have effluent treatment ponds (PCD, 2002). The carrying capacity of the estuaries and the canals, not the coastal sea, are considered since the nutrient stock effect to the sea is negligible for Andaman where the study site is located (Pongthanapanich, 2005). The effluent discharge constraints are formulated to restrict the allocation of land for shrimp farming. On the other hand, S2 assumes that the effluent is treated as to comply with the required effluent standard, which has been recently enacted for coastal aquaculture including shrimp farming.[3] This scenario represents the case when the effluent standard is successfully implemented. Therefore, the effluent discharge constraints are dropped in this scenario. Rather the effluent treatment cost of around 7 THB/kg (see PCD, 2002) is accounted as part of the farm operating cost. In S3, the combination of carrying capacity and effluent standard is considered.

Table 5. Model scenarios based on various schemes of shrimp farm externality management

Scenarios	NPB objective	NEB objective	Constraints of land availability	Constraints of effluent discharge from shrimp farms	Constraints of rice consumption
S1: Carrying capacity	Not account for externalities (not impose green taxes)	Cover mangrove indirect benefits and external costs of shrimp farms	Restricted	Restricted (consider the carrying capacity of receiving waters but not consider the effluent standard)	Restricted
S2: Effluent standard	Not account for externalities (not impose green taxes)	Cover mangrove indirect benefits and external costs of shrimp farms	Restricted	Not restricted (not consider the carrying capacity of receiving waters but consider the effluent standard)	Restricted
S3: Combined S1&S2	Not account for externalities (not impose green taxes)	Cover mangrove indirect benefits and external costs of shrimp farms	Restricted	Restricted (consider both the carrying capacity and the effluent standard)	Restricted

3 Effluent standard for Thailand's coastal aquaculture is published in the Royal Government Gazette, Vol. 121, Part 49 D, dated May 1, B.E.2547(2004). The details are available at http://www.pcd.go.th/info_serv/en_reg_std_water04.html#s11.

S4: Combined S1&Green tax	Account for externalities (impose green taxes)	Cover mangrove indirect benefits	Restricted	Restricted (the same to S1)	Restricted

Note: See Appendix 1 and 2 for mangrove benefits and shrimp farm externalities.

Moreover, in S4 the arrays of the coefficients in both objective functions are changed. This scenario aims to explore the case when the external costs of Thai shrimp farming (see Appendix 2) are internalized through the imposition of a green tax proposed by Pongthanapanich (2005). The carrying capacity is also considered in this scenario.

4.4. Constraints and Parameters

As to avoid a clutter model, the high mobility of labors and capitals is presumed. These production inputs are unlikely to be limiting factors in CLU optimization as the results shown in Kantangkul (2000). Three types of relevant constraints considered are described in the following.

Using the information provided in Table 2, the land availability restriction of 24 constraints is defined (i=1,2,3,…24), see Table 3. For example, in row 1 (i=1) total area available for the three competing activities, i.e. oil palm (X_1), rubber (X_2) and shrimp farming (X_3) in existing abandoned paddy in aquaculture zone (Aa) is 1,907 rai (b_1). In row 2, there is 6,439 rai (b_2) of existing mangrove in aquaculture zone (Am) can be conserved (X_4) and/or converted into shrimp farms (X_5).

For effluent discharge constraints, the required effluent standard of ammonia (NH_3-N) at 1.1 mg/l is used as a proxy for the calculation of maximum allowable load for shrimp farm discharge in the watercourses.[4] The calculation is then in line with the data of water body areas surrounding each of the ELU in

4 This study uses ammonia as an indicator as to comply with Thailand's coastal water quality standards (http://www.pcd.go.th/info_serv/en_reg_std_water02.html).

all selected zones. Assuming 2 meters depth of the receiving waters, the allowable loads obtained are: 68 (apd), 85330 (mgv), 5347 (oil), 3696 (rub), 2168 (srp) and 0 (tpd) kg-NH_3. The zero allowable load in existing paddy field implies that converting the area to shrimp farms is not environmentally viable. This is due to the fact that there is no access to the receiving waters for effluent discharge. These values are set as the RHS parameters (b_i).

PCD (2002) reported that the average concentration of ammonia in effluent water discharge from intensive farms during harvest and without prior treatment is around 1.283 mg/l. Together with the data of discharge volume and pond area obtained from the same study, it can be reckoned that the ammonia discharged is around 2.03 kg/rai-farm area/crop.[5] This is the coefficient (a_{ij}) of effluent discharge constraints in S1. For S3, the coefficient is 1.74 kg/rai-farm area/crop calculated based on the discharge load concentration that is equivalent to the effluent standard.

The above setting is assumed that during the peak season all shrimp farms within the area discharge the effluent in the same period. Note also that the allowable loads can be derived directly by using the information on assimilative capacity and waste load allocation, all of which require a site-specific data as well as a suitable water quality model (Simachaya, 2000). However, neither these types of data nor the estuarine water model for the study site are available. To relax the above assumption and the uncertainty, sensitivity analysis is also conducted here. The consequences of change in the allowable load for shrimp farming can then be investigated.

Lastly, rice consumption constraints are set by the minimum paddy supply required from each zone. This serves the coastal households' consumption that relies on local production. The average paddy yield of 300 kg/rai/year is defined as the coefficient (a_{ij}). The demand for coastal rice at 10% of total coastal consumption is assumed. The average rice consumption of 106 kg per

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5 The proportion of pond area per total farm area is around 0.7.

capita was estimated for Thailand (Isvilanonda and Poapongsakorn, 1995). Use this information and apply paddy-rice conversion factor of 0.66 for the calculation of the RHS parameters, which is also based on the share of paddy production from the existing area in each zone. The parameters obtained are: 903.9 8.4 898.3 84.0 tons/year from AQZ, MBZ, PDZ and ROZ, respectively. Furthermore, it can be argued that it may be more efficient to use the coastal land for other uses rather than for paddy production. Thus, the consequences on optimal land use options are also investigated when these constraints are dropped.

4.5. *The Model*

Based on the above setting, the mathematical model can be formulated as follows:

$$\text{Maximize NPB} = \sum_{j=1}^{65} c_{j1} X_j$$

$$\text{Maximize NEB} = \sum_{j=1}^{65} c_{j2} X_j$$

Subject to:

I. Land availability constraints (for all scenarios; see also Table 2 and 3). For row 5 and 17 the "no greater than" sign (≤) is set instead since these constraints are bound to the attainment of the feasible solutions given the corresponding effluent discharge constraint (i=29).

i=1 (Aa) $\sum_{j=1}^{3} X_j = 1{,}907$

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i=24 (Rt) $\sum_{j=63}^{65} X_j = 521$

II. Effluent discharge constraints (a_{ij}=2.03 for S1 and S4 and 1.74 for S3) i=25 (apd) $\sum_j a_{ij} X_j \leq 68$; j = 3, 16, 36 and 50

i=26 (mgv) $\sum_j a_{ij} X_j \leq 85330$; j = 5, 20, 40 and 54

i=27 (oil) $\sum_j a_{ij} X_j \leq 5347$; j = 7, 23 and 56

i=28 (rub) $\sum_j a_{ij} X_j \leq 3696$; j = 9, 26 and 58

i=29 (srp) $\sum_j a_{ij} X_j \leq 2168$; j = 10, 28, 43 and 61

i=30 (tpd) $\sum_j a_{ij} X_j \leq 0$; j = 11, 32, 46 and 64

III. Rice consumption constraints (for all scenarios)

i=31 (AQZ) $\sum_j 0.3 X_j \geq 903.9$; j = 12

i=32 (MBZ) $\sum_j 0.3 X_j \geq 8.4$; j = 33

i=33 (PDZ) $\sum_j 0.3 X_j \geq 898.3$; j = 47

i=34 (ROZ) $\sum_j 0.3 X_j \geq 84.0$; j = 65

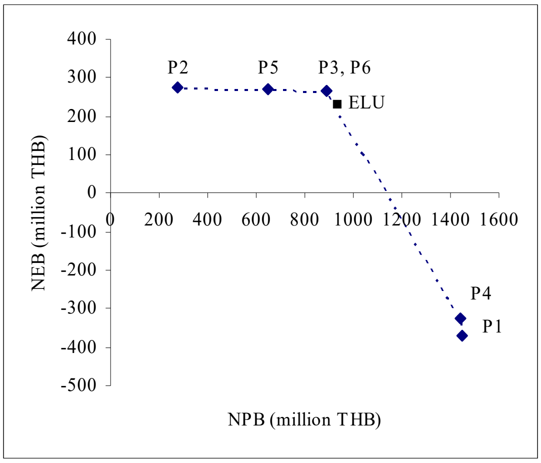
IV. Nonnegativity constraints

$X_j \geq 0$; j = 1,2,3,…,65

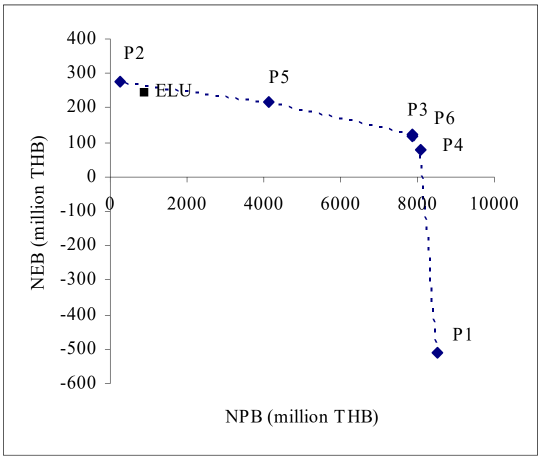
5. Results

The efficient set of CLU options are found at P1, P2,…, P6 for all scenarios (see Appendix 3-6 and Figure 2). P1 and P2 represent the payoff results when a single objective is optimized, i.e. maximum NPB and maximum NEB, respectively. In S1, S3 and S4, the entire efficient set is found on the segment P3P4 for S1, S3 and S4 plus P2P3 for S4. The iteration stops at P6 as the approximation gives zero allowable error, that is, P6 gives the same solutions as P3 (see Solving Techniques). The tradeoff rates of P3P5 and P5P2 show that NPB significantly increases with a slight decrease of NEB (Figure 2). Particularly in S4, the unbounded tradeoff occurs between these options. Meanwhile, P1P4 gives a proportionally larger loss of NEB than that of other segments when NPB increases. The results suggest that the proper efficient solutions of these scenarios to be further considered are those locate along the segment P3P4. For S2, although the entire set is not calculated, the approximated Pareto frontier obtained provides sufficient information for the interpretation. The segment P3P5, P5P2 as well as P1P4 are not further considered for the same reasons described above. This leaves P4P6 and P6P3 to be discusses in details.

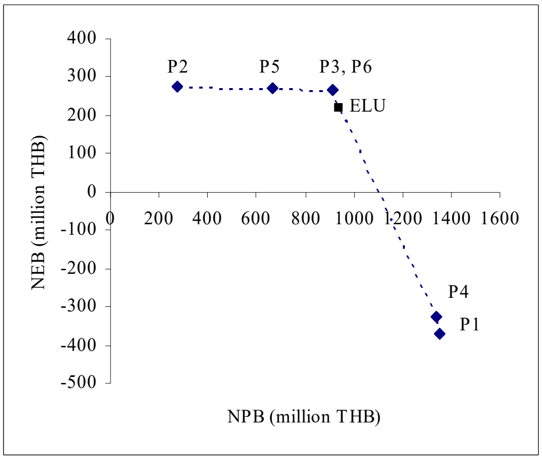
Figure 2. ***Approximated Pareto frontiers and tradeoff rates in various scenarios***



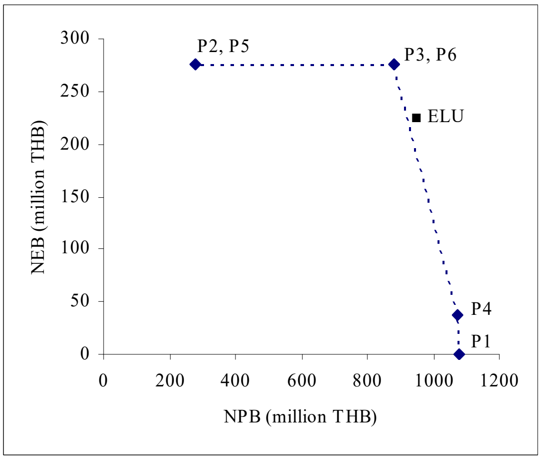
S1:Tradeoffs	P1P4	**P4P3(6)**	P3(6)P5	P5P2
ΔNEB/ΔNPB	-4.2	**-1.1**	0.0	0.0
ΔNPB/ΔNEB	-0.2	-0.9	-51.9	-87.8



S2:Tradeoffs	P1P4	**P4P6**	**P6P3**	P3P5	P5P2
ΔNEB/ΔNPB	-1.4	**-0.2**	**-0.1**	0.0	0.0
ΔNPB/ΔNEB	-0.7	-5.5	-7.3	-38.7	-67.2



S3:Tradeoffs	P1P4	**P4P3(6)**	P3(6)P5	P5P2
ΔNEB/ΔNPB	-4.2	**-1.4**	0.0	0.0
ΔNPB/ΔNEB	-0.2	-0.7	-44.9	-79.4



S4:Tradeoffs	P1P4	**P4P3(6)**	P3(6)P5(2)
ΔNEB/ΔNPB	-7.6	**-1.2**	0.0
ΔNPB/ΔNEB	-0.1	-0.8	infinity

Note: 1) NPB and NEB are denoted as net private benefit and net environmental benefit, respectively.

2) ELU point represents the benefits obtained from existing land use.

Broadly, the same results in decision space, $\underline{x}$, are obtained from S1 and S4, which results in the same amount of total benefit in each option, except P5. However, S4 gives higher NEB but lower NPB than that from S1 as a consequence of the internalization of external costs (see Appendix 3 and 6). Not surprisingly, the number of shrimp farms increases in S3 (when the effluent standard is also in place) as compared to S1 and S4. The magnitude of the results from S2 is radically larger than from other scenarios.

Table 6 presents the selected OCLU options that are elaborated as follows. In S1, S3 and S4, the tradeoff between P3 and P4 with respect to shrimp farming and mangrove is very significant (see Item 1). The option P3 of these scenarios implies all existing mangroves be kept (11,844 rai), so do S2 (except at P1).

Table 6. Selected optimal coastal land use (OCLU) options of each scenario

Items	Activities [1/]	Existing land use [2/]	S1P3 =S4P3	S1P4 =S4P4	S2P3	S2P4	S2P6	S3P3	S3P4
1.OCLU in all zones classified by activities (rai)	mgrXx	0	3644	3644	3168	0	2868	3644	3644
	mgvXx	11844	11844	0	11844	11844	11844	11844	0
	oilXx	28164	33051	33051	8064	8064	8064	32606	32606
	rubXx	109105	105424	105424	50420	50420	50420	105121	105121
	srpXx	7184	5556	17400	93040	96208	93340	6482	18326
	tpdXx	11950	9006	9006	6315	6315	6315	9006	9006
	sum	**172851**[3/]	**168525**	**168525**	**172851**	**172851**	**172851**	**168703**	**168703**
2. Land use change: Item 1 minus ELU (rai)	mgrXx		3644	3644	3168	0	2868	3644	3644
	mgvXx		0	-11844	0	0	0	0	-11844
	oilXx		4887	4887	-20100	-20100	-20100	4442	4442
	rubXx		-3681	-3681	-58685	-58685	-58685	-3985	-3985
	srpXx		-1628	10216	85856	89024	86156	-702	11142
	tpdXx		-2944	-2944	-5635	-5635	-5635	-2944	-2944
3. Item 2 in % of ELU	mgrXx					0%			
	mgvXx		0%	-100%	0%	0%	0%	0%	-100%
	oilXx		17%	17%	-71%	-71%	-71%	16%	16%
	rubXx		-3%	-3%	-54%	-54%	-54%	-4%	-4%
	srpXx		-23%	142%	1195%	1239%	1199%	-10%	155%
	tpdXx		-25%	-25%	-47%	-47%	-47%	-25%	-25%
4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	apd	33	33	4336	4604	4604	39	39
	srpXm	mgv	0	11844	0	0	0	0	11844
	srpXo	oil	2634	2634	20100	20100	20100	3073	3073
	srpXr	rub	1821	1821	56825	58685	56825	2124	2124
	srpXs [4/]	srp=7,184	1068	1068	6176	7184	6176	1246	1246
	srpXt	tpd	0	0	5603	5635	5635	0	0
	sum		**5556**	**17400**	**93040**	**96208**	**93340**	**6482**	**18326**

5. OCLU of shrimp farming in AQZ (rai)	For all ELU (srpAx)		5556	11995	34809	34809	34809	6482	12921
	For existing srp (srpAs)		1068	1068	5080	5080	5080	1246	1246
	srpAx-srpAs		**4488**	**10927**	**29729**	**29729**	**29729**	**5236**	**11675**
6. OCLU correspond with CLDZ [5/] (rai)	srp in AQZ (srpAx)		5556	11995	34809	34809	34809	6482	12921
	mgr in MBZ (mgrMx)		3644	3644	3168	0	2868	3644	3644
	mgv in MBZ (mgvMm)		4650	0	4650	4650	4650	4650	0
	tpd in PDZ (tdpPt)		2994	2994	2994	2994	2994	2994	2994
	oil in ROZ (oilRx)		13831	13831	0	0	0	13831	13831
	rub in ROZ (rubRx=rubRr)		38685	38685	0	0	0	38685	38685
7. Benefits (million THB/year)			S1P3 &S4P3	S1P4 &S4P4	S2P3	S2P4	S2P6	S3P3	S3P4
	Z1=NPB	934	890 881	1438 1075	7860	8099	7886	912	1342
	Z2=NEB	222	267 276	-326 37	122	80	118	265	-328
	Z1+Z2	**1156**	**1157** **1157**	**1112** **1112**	**7982**	**8178**	**8004**	**1178**	**1014**

Note: [1/] Refer to Table 3 for the abbreviations.

[2/] Refer to Table 2 for the number of area of existing land use (ELU).

[3/] Including existing abandoned paddy area (Xa) of 4604 rai.

[4/] Area of existing shrimp farming be optimally continued.

[5/] Total area of each zone in CLDZ: AQZ=44261, MBZ=8322, PDZ=66985 and ROZ=53283.

These figures cover the areas of apd, mgv, oil, rub, srp and tpd (from Table 2).

If the mangrove were converted, it would entail high marginal costs (shadow costs) in the range of 14,550-46,590 THB/rai/year (Table 7). In contrast, P4 in S1, S3 and S4 shows that all mangroves can be converted to farms. However, keeping the additional stand mangrove would entail low marginal costs of 2,319-2,578 THB/rai/year.

Table 7. Shadow costs of shrimp farming and mangrove in existing mangrove of all zones

Activities	S1P3	S1P4	S2P3	S2P4	S2P6	S3P3	S3P4	S4P3	S4P4
Shrimp farming (srpXm)									
- Optimum solution (rai)	0	11844	0	0	0	0	11844	0	11844
- Shadow costs (THB/rai/year)	**24640**	**0**	**46590**	**15570**	**43640**	**28310**	**0**	**14550**	**0**
Mangrove (mgvXm)									
- Optimum solution (rai)	11844	0	11844	11844	11844	11844	0	11844	0
- Shadow costs (THB/rai/year)	**0**	**2578**	**0**	**0**	**0**	**0**	**2319**	**0**	**2537**

The results also suggest the reallocation of land especially for shrimp farming (see Item 2 and 3 in Table 6). In S1, S3 and S4, oil palm plantation can increase 16-17% of the existing area. More specifically, some existing oil palm can be converted to shrimp farms and some plantation in mangrove zone (MBZ) to mangrove reforestation, while a new plantation can be expanded to the abandoned paddy area. In contrast, S2 suggests the existing oil palm area be reduced by 71%. Given a minimum level of local paddy production, the paddy filed is suggested be reduced, i.e. 25% in S1, S3 and S4; and 47% in S2. Furthermore, there is a slight decrease of rubber plantation, i.e. 3-4% in S1, S3 and S4, but 54% in S2. In short, S2 implies vast agricultural lands be converted to shrimp farms. S1, S3 and S4 also show this pattern but to a lesser extent. Nonetheless, the conversion of paddy production to shrimp farming is not feasible in these three scenarios (considering the carrying capacity) since there is no access to the receiving waters for effluent discharges in paddy areas.

S2 suggests more than 85% of existing shrimp farms be remained while other scenarios suggest 15-17% (srpXs in Item 4, Table 6). This is found to be those farms in aquaculture zone, AQZ (srpAs in Item 5). In addition, S2 shows that the overall number of shrimp farm can optimally increase far more than the existing number (see Item 4).

The results of OCLU activities are sorted in corresponding with their designated zones under CLDZ. This shows that the optimal shrimp farms (5,556-34,809 rai) in AQZ, is lower than recommended (44,261 rai). The differences are very significant particularly for S1, S3 and S4. This same interpretation is implied for paddy production. See details in Item 6.

For sensitivity analysis, S1 (P3 and P4) is chosen to base the analysis for the reasons as discussed in next section. It shows that when the allowable load of ammonia from shrimp farm discharge is changed, the results also change intuitively (Table 8). That is increasing the allowable load would increase the optimum shrimp farm area from base case, some of which results from remaining the existing farms (only in AQZ) and some from converting the oil palm and rubber plantation. Conversely, the lower the allowable load, the lower the number of optimum shrimp farms.

Table 8. Selected optimal coastal land use (OCLU) options when change in nutrient allowable load for shrimp farming

Items	Activities [1/]	S1P3					S1P4				
		dec50%	dec25%	base case	inc25%	inc50%	dec50%	dec25%	base case	inc25%	inc50%
1.OCLU in all zones classified by activities (rai)	mgrXx	3644	3644	3644	3644	3644	3644	3644	3644	3644	3644
	mgvXx	11844	11844	11844	11844	11844	0	0	0	0	0
	oilXx	34384	33718	33051	32383	31717	34384	33718	33051	32383	31717
	rubXx	106335	105879	105424	104969	104514	106335	105879	105424	104969	104514
	srpXx	2778	4167	5556	6946	8334	14622	16011	17400	18790	20178
	tpdXx	9006	9006	9006	9006	9006	9006	9006	9006	9006	9006
	sum	**167991**	**168258**	**168525**	**168792**	**169059**	**167991**	**168258**	**168525**	**168792**	**169059**
2. Land use change: Item 1 minus ELU [2/] (rai)	mgrXx	3644	3644	3644	3644	3644	3644	3644	3644	3644	3644
	mgvXx	0	0	0	0	0	-11844	-11844	-11844	-11844	-11844
	oilXx	6220	5554	4887	4219	3553	6220	5554	4887	4219	3553
	rubXx	-2770	-3226	-3681	-4136	-4591	-2770	-3226	-3681	-4136	-4591
	srpXx	-4406	-3017	-1628	-238	1150	7438	8827	10216	11606	12994
	tpdXx	-2944	-2944	-2944	-2944	-2944	-2944	-2944	-2944	-2944	-2944
3. Item 2 in % of ELU	mgrXx [3/]										
	mgvXx	0%	0%	0%	0%	0%	-100%	-100%	-100%	-100%	-100%
	oilXx	22%	20%	17%	15%	13%	22%	20%	17%	15%	13%
	rubXx	-3%	-3%	-3%	-4%	-4%	-3%	-3%	-3%	-4%	-4%
	srpXx	-61%	-42%	-23%	-3%	16%	104%	123%	142%	162%	181%
	tpdXx	-25%	-25%	-25%	-25%	-25%	-25%	-25%	-25%	-25%	-25%

4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	17	25	33	42	50	17	25	33	42	50
	srpXm	0	0	0	0	0	11844	11844	11844	11844	11844
	srpXo	1317	1975	2634	3293	3951	1317	1975	2634	3293	3951
	srpXr	910	1366	1821	2276	2731	910	1366	1821	2276	2731
	srpXs [4/]	534	801	1068	1335	1602	534	801	1068	1335	1602
	srpXt	0	0	0	0	0	0	0	0	0	0
	sum	**2778**	**4167**	**5556**	**6946**	**8334**	**14622**	**16011**	**17400**	**18790**	**20178**
5. OCLU of shrimp farming in AQZ (rai)	srpAx	2778	4167	5556	6946	8334	9217	10606	11995	13385	14773
	srpAs	534	801	1068	1335	1602	534	801	1068	1335	1602
	srpAx-srpAs	**2244**	**3366**	**4488**	**5611**	**6732**	**8683**	**9805**	**10927**	**12050**	**13171**
6. OCLU correspond with CLDZ [5/] (rai)	srpAx	2778	4167	5556	6946	8334	9217	10606	11995	13385	14773
	mgrMx	3644	3644	3644	3644	3644	3644	3644	3644	3644	3644
	mgvMx	4650	4650	4650	4650	4650	0	0	0	0	0
	tdpPt	2994	2994	2994	2994	2994	2994	2994	2994	2994	2994
	oilRx	13831	13831	13831	13831	13831	13831	13831	13831	13831	13831
	rubRx	38685	38685	38685	38685	38685	38685	38685	38685	38685	38685
7. Benefits (million THB/yr)	Z1=NPB	583	736	890	1043	1197	1131	1285	1438	1592	1745
	Z2=NEB	271	269	267	265	262	-322	-324	-326	-328	-330
	Z1+Z2	**854**	**1006**	**1157**	**1308**	**1459**	**810**	**961**	**1112**	**1263**	**1414**

Note: [1/] Refer to Table 3 for the abbreviations.

[2/] Refer to Table 2 for the number of area of existing land use (ELU), see also Table 6.

[3/] Introduced activity.

[4/] Area of existing shrimp farming be optimally continued.

[5/] Total area of each zone in CLDZ: AQZ=44261, MBZ=8322, PDZ=66985 and ROZ=53283. These figures cover the areas of apd, mgv, oil, rub, srp and tpd (from Table 2).

When rice consumption constraints are not restricted (that is, disregarding the self-sufficiency target), the optimal paddy production decreases from 9,006 rai (in S1P3 and S1P4) to 5,704 rai. NPB is improved while NEB is unchanged. Around half of the existing area can be optimally reduced. The next best alternative use for the reduced area is oil palm rather than rubber plantation or shrimp farming. Nevertheless, the existing area in AQZ remains since there is no other alternative and no access to the receiving waters for shrimp farm discharges in this area. See details in Table 9.

Table 9. Selected optimal coastal land use (OCLU) options when without the consideration of rice consumption (II)

Items	Activities [1/]	S1P3			S1P4		
		I (Base case)	II	Change (I-II)	I (Base case)	II	Change (I-II)
1.OCLU in all zones classified by activities (rai)	mgrXx	3644	3672	-28	3644	3672	-28
	mgvXx	11844	11844	0	0	0	0
	oilXx	33051	36325	-3274	33051	36325	-3274
	rubXx	105424	105424	0	105424	105424	0
	srpXx	5556	5556	0	17400	17400	0
	tpdXx	9006	5704	3302	9006	5704	3302
	sum	**168525**	**168525**	**0**	**168525**	**168525**	**0**
2. Land use change: Item 1 minus ELU [2/] (rai)	mgrXx	3644	3672	-28	3644	3672	-28
	mgvXx	0	0	0	-11844	-11844	0
	oilXx	4887	8161	-3274	4887	8161	-3274
	rubXx	-3681	-3681	0	-3681	-3681	0
	srpXx	-1628	-1628	0	10216	10216	0
	tpdXx	-2944	-6246	3302	-2944	-6246	3302
3. Item 2 in % of ELU	mgrXx [3/]						
	mgvXx	0%	0%	0%	-100%	-100%	0%
	oilXx	17%	29%	-12%	17%	29%	-12%
	rubXx	-3%	-3%	0%	-3%	-3%	0%
	srpXx	-23%	-23%	0%	142%	142%	0%
	tpdXx	-25%	-52%	27%	-25%	-52%	27%

4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	33	33	0	33	33	0
	srpXm	0	0	0	11844	11844	0
	srpXo	2634	2634	0	2634	2634	0
	srpXr	1821	1821	0	1821	1821	0
	srpXs [4/]	1068	1068	0	1068	1068	0
	srpXt	0	0	0	0	0	0
	sum	**5556**	**5556**	**0**	**17400**	**17400**	**0**
5. OCLU of shrimp farming in AQZ (rai)	srpAx	5556	5556	0	11995	11995	0
	srpAs	1068	1068	0	1068	1068	0
	srpAx-srpAs	4488	4488	0	10927	10927	0
6. OCLU correspond with CLDZ [5/] (rai)	srpAx	5556	5556	0	11995	11995	0
	mgrMx	3644	3672	-28	3644	3672	-28
	mgvMx	4650	4650	0	0	0	0
	tdpPt	2994	0	2994	2994	0	2994
	oilRx	13831	14111	-280	13831	14111	-280
	rubRx	38685	38685	0	38685	38685	0
7. Benefits (million THB/yr)	Z1=NPB	890	905	-15	1438	1453	-15
	Z2=NEB	267	267	0	-326	-326	0
	Z1+Z2	**1157**	**1172**	**-15**	**1112**	**1127**	**-15**

Note: [1/] Refer to Table 3 for the abbreviations.

[2/] Refer to Table 2 for the number of area of existing land use (ELU), see also Table 6. [3/] Introduced activity.

[4/] Area of existing shrimp farming be optimally continued.

[5/] Total area of each zone in CLDZ: AQZ=44261, MBZ=8322, PDZ=66985 and ROZ=53283. These figures cover the areas of apd, mgv, oil, rub, srp and tpd (from Table 2).

6. Discussion

The policy solution for the dilemma between conserving the remaining mangrove (under the cabinet resolution on 22 August 2002) and developing the mangrove for shrimp farms (which is allowed under the resolution on 15 December 1987) critically relies on the decision maker’s preference. Promoting the development coincides with option P1 and P4 in S1, S3, and S4 as well as P1 in S2, all of which leans on the private benefits, while the rest of the options encourage the conservation. However, base on the information of shadow costs and under the uncertainty of land use impacts on coastal systems, P3 is deemed to be a promising proactive option.

The management design based on the aquaculture effluent standard alone, i.e. S2, does not utterly guarantee the environmentally friendly outcome. Although this scheme encourages mangrove conservation (except P1), the results show the feasibility of high expansion of shrimp farms (i.e. from 7,184 to more than 93,000 rai). This level of expansion, however, would be beyond the carrying capacity of receiving waters (compare S2 with S3 in Table 6). The overcapacity will not be signaled until the problem, that is, the disease outbreak occurs. Thus, the implementation of effluent standard should be combined with the carrying capacity scheme, i.e. S3.

S3 offers higher optimal shrimp farms (due to the lower discharge load concentration as a consequence of the compliance with effluent standard) than that from using only the carrying capacity scheme, i.e. S1. However, the benefits obtained are not significantly different. Besides, S1 does not require an extra control of effluent discharge. Therefore, S1 is deemed as a more conservative and promising plan than S3. The notably change in benefits of S1 occurs, when a green tax is combined, i.e. S4. S4 leads to nonnegative NEB since the externalities are internalized. However, the OCLU patterns do not differ between S1 and S4. The taxation is recommended as a combined measure with carrying capacity particularly when the decision making tends to go for development rather than conservation.

Finally, further technical researches to seek for suitable land use alternatives that can substitute existing shrimp farms and existing paddy field particularly in aquaculture zone should be encouraged. Generating more alternative use for these areas could perhaps move the Pareto frontier forward.

7. Conclusion

The options for OCLU and tradeoff information in various scenarios of shrimp farm externality management are explored. The potential land use activities as decision variables are defined within the existing use and CLDZ framework. The tradeoffs among the options are measured in two-dimension objective space, i.e. maximum NPB and NEB. The coefficients of objective functions, constraint set and associated parameters are assigned correspondingly to the management scenarios. All scenarios indicate that the benefit from present CLU pattern in Krabi is close to the efficient level (Pareto frontier). However, the reallocation of land use is required, if the coastal planning aims to reach the proper efficient outcome. This study provides the results to base the revision of CLDZ. Among several management schemes to control externalities from shrimp farming, the designated aquaculture zone on the basis of carrying capacity is important. Meanwhile, the combined measures of carrying capacity and corrective taxation would lead to economically and environmentally responsible aquaculture. The present adoption of aquaculture effluent standard alone does not guarantee these outcomes.

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Appendix 1.

Economic values of mangrove in Southern Thailand

Items	Values (THB/rai/yr)	Note
Direct use value (woods & non-woods)	1,938	Obtained from Sathirathai (1998). The survey was conducted in Tha Po village, Surat Thani province in 1996. The value is based on the assumption of mangrove-dependent village.
Indirect use value		
- Off-shore fishery linkage	272	Obtained from Sathirathai (1998). The study measures the net welfare loss due to the decreasing of stand mangrove. The Eillis-Fisher-Freeman model is applied. The value is based on the case of open-access regime and the price elasticity of demand for fishery product equals -2
- Carbon sequestration	341	Obtained from Sathirathai (1998). The total biomass was calculated and converted to derive carbon equivalent.
- Coastal erosion protection	18,310	Modified from Sathirathai and Barbier (2004). The demand for engineering work to stabilize the shoreline is used as a proxy value.
Sum	20,861	

Appendix 2.

Environmental costs of coastal shrimp farming in Southern Thailand

Impacts	Ex-mangrove (THB/rai/yr)	Outside mangrove (THB/rai/yr)	Note
Effect of nutrient load to the sea	0	0	Pongthanapanich (2005) applies dynamic-constraint optimization model to measure a green tax to be imposed on Thai shrimp farming. The results indicate that the marginal cost of nutrient effect to the Andaman Sea is negligible.
Abandoned shrimp farm	6,378 [1/]	1,385 [2/]	[1/] Based on Sathirathai and Barbier (2004), the reclamation costs of abandoned farms including mangrove seedling, and maintenance of 52,736 THB/rai for initial cost and 755 THB/rai for annual cost are used as proxy. [2/] Use remediation cost of pond soil as proxy value. The present value of the cost is 9,296 THB/rai (t=10; r=8%).
Mangrove forgone benefits	20,861		See Appendix 1.
Total	27,239	1,385	

Note: 1) Shrimp farming in ex-mangrove and outside mangrove respectively means by converting mangrove and converting agricultural land into farms.

2) The review of environmental impacts of shrimp farming in ex-mangrove and outside mangrove in Thailand are provided by Pongthanapanich (2005).

Appendix 3.

Optimal coastal land use (OCLU) options for scenario 1

Decision Variables		S1P1	S1P2	S1P3	S1P4	S1P5	S1P6
1	oilAa	1874	1907	1874	1874	1907	1874
2	rubAa	0	0	0	0	0	0
3	srpAa	33	0	33	33	0	33
4	mgvAm	0	6439	6439	0	6439	6439
5	srpAm	6439	0	0	6439	0	0
6	oilAo	4357	6991	4357	4357	4357	4357
7	srpAo	2634	0	2634	2634	2634	2634
8	rubAr	16319	18140	16319	16319	18140	16319
9	srpAr	1821	0	1821	1821	0	1821
10	srpAs	60	0	1068	1068	0	1068
11	srpAt	0	0	0	0	0	0
12	tpdAt	5704	5704	5704	5704	5704	5704
13	mgrMa	0	268	268	268	268	268
14	oilMa	268	0	0	0	0	0
15	rubMa	0	0	0	0	0	0
16	srpMa	0	0	0	0	0	0
17	mgvMm	0	4650	4650	0	4650	4650
18	oilMm	0	0	0	0	0	0
19	rubMm	0	0	0	0	0	0
20	srpMm	4650	0	0	4650	0	0
21	mgrMo	0	476	476	476	476	476
22	oilMo	476	0	0	0	0	0
23	srpMo	0	0	0	0	0	0
24	mgrMr	0	1860	1860	1860	1860	1860
25	rubMr	1860	0	0	0	0	0
26	srpMr	0	0	0	0	0	0
27	mgrMs	0	1008	1008	1008	1008	1008
28	srpMs	1008	0	0	0	0	0
29	mgrMt	0	32	32	32	32	32
30	oilMt	32	0	0	0	0	0
31	rubMt	0	0	0	0	0	0
32	srpMt	0	0	0	0	0	0
33	tpdMt	28	28	28	28	28	28
34	oilPa	2254	2254	2254	2254	2254	2254
35	rubPa	0	0	0	0	0	0
36	srpPa	0	0	0	0	0	0
37	mgvPm	0	268	268	0	268	268
38	oilPm	0	0	0	0	0	0
39	rubPm	0	0	0	0	0	0
40	srpPm	268	0	0	268	0	0
41	oilPo	8064	8064	8064	8064	8064	8064
42	rubPr	50420	50420	50420	50420	50420	50420
43	srpPs	0	0	0	0	0	0

Decision Variables		S1P1	S1P2	S1P3	S1P4	S1P5	S1P6
44	oilPt	2671	2671	2671	2671	2671	2671
45	rubPt	0	0	0	0	0	0
46	srpPt	0	0	0	0	0	0
47	tpdPt	2994	2994	2994	2994	2994	2994
48	oilRa	175	175	175	175	175	175
49	rubRa	0	0	0	0	0	0
50	srpRa	0	0	0	0	0	0
51	mgvRm	0	487	487	0	487	487
52	oilRm	0	0	0	0	0	0
53	rubRm	0	0	0	0	0	0
54	srpRm	487	0	0	487	0	0
55	oilRo	12633	12633	12633	12633	12633	12633
56	srpRo	0	0	0	0	0	0
57	rubRr	38685	38685	38685	38685	38685	38685
58	srpRr	0	0	0	0	0	0
59	oilRs	782	782	782	782	782	782
60	rubRs	0	0	0	0	0	0
61	srpRs	0	0	0	0	0	0
62	oilRt	241	241	241	241	241	241
63	rubRt	0	0	0	0	0	0
64	srpRt	0	0	0	0	0	0
65	tpdRt	280	280	280	280	280	280
	sum	**167517**	**167457**	**168525**	**168525**	**167457**	**168525**
1.OCLU in all zones classified by activities (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	0	11844	11844	0	11844	11844
	oilXx	33827	35718	33051	33051	33084	33051
	rubXx	107284	107245	105424	105424	107245	105424
	srpXx	17400	0	5556	17400	2634	5556
	tdpXx	9006	9006	9006	9006	9006	9006
	sum	**167517**	**167457**	**168525**	**168525**	**167457**	**168525**
2. Land use change: Item 1 minus ELU (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	-11844	0	0	-11844	0	0
	oilXx	5663	7554	4887	4887	4920	4887
	rubXx	-1821	-1860	-3681	-3681	-1860	-3681
	srpXx	10216	-7184	-1628	10216	-4550	-1628
	tdpXx	-2944	-2944	-2944	-2944	-2944	-2944
3. Item 2 in % of ELU	mgrXx	0%					
	mgvXx	-100%	0%	0%	-100%	0%	0%
	oilXx	20%	27%	17%	17%	17%	17%
	rubXx	-2%	-2%	-3%	-3%	-2%	-3%
	srpXx	142%	-100%	-23%	142%	-63%	-23%
	tdpXx	-25%	-25%	-25%	-25%	-25%	-25%

Decision Variables		S1P1	S1P2	S1P3	S1P4	S1P5	S1P6
4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	33	0	33	33	0	33
	srpXm	11844	0	0	11844	0	0
	srpXo	2634	0	2634	2634	2634	2634
	srpXr	1821	0	1821	1821	0	1821
	srpXs	1068	0	1068	1068	0	1068
	srpXt	0	0	0	0	0	0
	sum	**17400**	**0**	**5556**	**17400**	**2634**	**5556**

5. OCLU of shrimp farming in AQZ (rai)	srpAx	10987	0	5556	11995	2634	5556
	srpAs	60	0	1068	1068	0	1068
	srpAx-srpAs	**10927**	**0**	**4488**	**10927**	**2634**	**4488**
6. OCLU correspond with CLDZ [5/] (rai)	srpAx	10987	0	5556	11995	2634	5556
	mgrMx	0	3644	3644	3644	3644	3644
	mgvMm	0	4650	4650	0	4650	4650
	tdpPt	2994	2994	2994	2994	2994	2994
	oilRx	13831	13831	13831	13831	13831	13831
	rubRx=rubRr	38685	38685	38685	38685	38685	38685
7. Benefits (million THB/year	Z1=NPB	1448	276	890	1438	647	890
	Z2=NEB	-368	276	267	-326	272	267
	Z1+Z2	**1080**	**552**	**1157**	**1112**	**918**	**1157**

Appendix 4.

Optimal coastal land use (OCLU) options for scenario 2

Decision Variables		S2P1	S2P2	S2P3	S2P4	S2P5	S2P6
1	oilAa	0	1907	0	0	0	0
2	rubAa	0	0	0	0	0	0
3	srpAa	1907	0	1907	1907	1907	1907
4	mgvAm	0	6439	6439	6439	6439	6439
5	srpAm	6439	0	0	0	0	0
6	oilAo	0	6991	0	0	0	0
7	srpAo	6991	0	6991	6991	6991	6991
8	rubAr	0	18140	0	0	18140	0
9	srpAr	18140	0	18140	18140	0	18140
10	srpAs	5080	0	5080	5080	5080	5080
11	srpAt	2691	0	2691	2691	2691	2691
12	tpdAt	3013	5704	3013	3013	3013	3013
13	mgrMa	0	268	268	0	268	0
14	oilMa	0	0	0	0	0	0
15	rubMa	0	0	0	0	0	0
16	srpMa	268	0	0	268	0	268
17	mgvMm	0	4650	4650	4650	4650	4650
18	oilMm	0	0	0	0	0	0
19	rubMm	0	0	0	0	0	0
20	srpMm	4650	0	0	0	0	0
21	mgrMo	0	476	0	0	476	0
22	oilMo	0	0	0	0	0	0
23	srpMo	476	0	476	476	0	476
24	mgrMr	0	1860	1860	0	1860	1860
25	rubMr	0	0	0	0	0	0
26	srpMr	1860	0	0	1860	0	0
27	mgrMs	0	1008	1008	0	1008	1008
28	srpMs	1008	0	0	1008	0	0
29	mgrMt	0	32	32	0	32	0
30	oilMt	0	0	0	0	0	0
31	rubMt	0	0	0	0	0	0
32	srpMt	32	0	0	32	0	32
33	tpdMt	28	28	28	28	28	28
34	oilPa	0	2254	0	0	0	0
35	rubPa	0	0	0	0	0	0
36	srpPa	2254	0	2254	2254	2254	2254
37	mgvPm	0	268	268	268	268	268
38	oilPm	0	0	0	0	0	0
39	rubPm	0	0	0	0	0	0
40	srpPm	268	0	0	0	0	0

Decision Variables		S2P1	S2P2	S2P3	S2P4	S2P5	S2P6
41	oilPo	8064	8064	8064	8064	8064	8064
42	rubPr	50420	50420	50420	50420	50420	50420
43	srpPs	314	0	314	314	314	314
44	oilPt	0	2671	0	0	0	0
45	rubPt	0	0	0	0	0	0
46	srpPt	2671	0	2671	2671	2671	2671
47	tpdPt	2994	2994	2994	2994	2994	2994
48	oilRa	0	175	0	0	0	0
49	rubRa	0	0	0	0	0	0
50	srpRa	175	0	175	175	175	175
51	mgvRm	0	487	487	487	487	487
52	oilRm	0	0	0	0	0	0
53	rubRm	0	0	0	0	0	0
54	srpRm	487	0	0	0	0	0
55	oilRo	0	12633	0	0	0	0
56	srpRo	12633	0	12633	12633	12633	12633
57	rubRr	0	38685	0	0	38685	0
58	srpRr	38685	0	38685	38685	0	38685
59	oilRs	0	782	0	0	0	0
60	rubRs	0	0	0	0	0	0
61	srpRs	782	0	782	782	782	782
62	oilRt	0	241	0	0	0	0
63	rubRt	0	0	0	0	0	0
64	srpRt	241	0	241	241	241	241
65	tpdRt	280	280	280	280	280	280
	sum	**172851**	**167457**	**172851**	**172851**	**172851**	**172851**
1.OCLU in all zones classified by activities (rai)	mgrXx	0	3644	3168	0	3644	2868
	mgvXx	0	11844	11844	11844	11844	11844
	oilXx	8064	35718	8064	8064	8064	8064
	rubXx	50420	107245	50420	50420	107245	50420
	srpXx	108052	0	93040	96208	35739	93340
	tdpXx	6315	9006	6315	6315	6315	6315
	sum	**172851**	**167457**	**172851**	**172851**	**172851**	**172851**
2. Land use change: Item 1 minus ELU (rai)	mgrXx	0	3644	3168	0	3644	2868
	mgvXx	-11844	0	0	0	0	0
	oilXx	-20100	7554	-20100	-20100	-20100	-20100
	rubXx	-58685	-1860	-58685	-58685	-1860	-58685
	srpXx	100868	-7184	85856	89024	28555	86156
	tdpXx	-5635	-2944	-5635	-5635	-5635	-5635
3. Item 2 in % of ELU	mgrXx	0%			0%		
	mgvXx	-100%	0%	0%	0%	0%	0%
	oilXx	-71%	27%	-71%	-71%	-71%	-71%
	rubXx	-54%	-2%	-54%	-54%	-2%	-54%
	srpXx	1404%	-100%	1195%	1239%	397%	1199%
	tdpXx	-47%	-25%	-47%	-47%	-47%	-47%

Decision Variables		S2P1	S2P2	S2P3	S2P4	S2P5	S2P6
4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	4604	0	4336	4604	4336	4604
	srpXm	11844	0	0	0	0	0
	srpXo	20100	0	20100	20100	19624	20100
	srpXr	58685	0	56825	58685	0	56825
	srpXs	7184	0	6176	7184	6176	6176
	srpXt	5635	0	5603	5635	5603	5635
	sum	**108052**	**0**	**93040**	**96208**	**35739**	**93340**
5. OCLU of shrimp farming in AQZ (rai)	srpAx	41248	0	34809	34809	16669	34809
	srpAs	5080	0	5080	5080	5080	5080
	srpAx-srpAs	**36168**	**0**	**29729**	**29729**	**11589**	**29729**
6. OCLU correspond with CLDZ 5/ (rai)	srpAx	41248	0	34809	34809	16669	34809
	mgrMx	0	3644	3168	0	3644	2868
	mgvMm	0	4650	4650	4650	4650	4650
	tdpPt	2994	2994	2994	2994	2994	2994
	oilRx	0	13831	0	0	0	0
	rubRx=rubRr	0	38685	0	0	38685	0
7. Benefits (million THB/year	Z1=NPB	8528	276	7860	8099	4124	7886
	Z2=NEB	-513	276	122	80	218	118
	Z1+Z2	**8015**	**552**	**7982**	**8178**	**4342**	**8004**

Appendix 5.

Optimal coastal land use (OCLU) options for scenario 3

Decision Variables		S3P1	S3P2	S3P3	S3P4	S3P5	S3P6
1	oilAa	1868	1907	1868	1868	1907	1868
2	rubAa	0	0	0	0	0	0
3	srpAa	39	0	39	39	0	39
4	mgvAm	0	6439	6439	0	6439	6439
5	srpAm	6439	0	0	6439	0	0
6	oilAo	3918	6991	3918	3918	3918	3918
7	srpAo	3073	0	3073	3073	3073	3073
8	rubAr	16016	18140	16016	16016	18140	16016
9	srpAr	2124	0	2124	2124	0	2124
10	srpAs	238	0	1246	1246	0	1246
11	srpAt	0	0	0	0	0	0
12	tpdAt	5704	5704	5704	5704	5704	5704
13	mgrMa	0	268	268	268	268	268
14	oilMa	268	0	0	0	0	0
15	rubMa	0	0	0	0	0	0
16	srpMa	0	0	0	0	0	0
17	mgvMm	0	4650	4650	0	4650	4650
18	oilMm	0	0	0	0	0	0
19	rubMm	0	0	0	0	0	0
20	srpMm	4650	0	0	4650	0	0
21	mgrMo	0	476	476	476	476	476
22	oilMo	476	0	0	0	0	0
23	srpMo	0	0	0	0	0	0
24	mgrMr	0	1860	1860	1860	1860	1860
25	rubMr	1860	0	0	0	0	0
26	srpMr	0	0	0	0	0	0
27	mgrMs	0	1008	1008	1008	1008	1008
28	srpMs	1008	0	0	0	0	0
29	mgrMt	0	32	32	32	32	32
30	oilMt	32	0	0	0	0	0
31	rubMt	0	0	0	0	0	0
32	srpMt	0	0	0	0	0	0
33	tpdMt	28	28	28	28	28	28
34	oilPa	2254	2254	2254	2254	2254	2254
35	rubPa	0	0	0	0	0	0
36	srpPa	0	0	0	0	0	0
37	mgvPm	0	268	268	0	268	268
38	oilPm	0	0	0	0	0	0
39	rubPm	0	0	0	0	0	0
40	srpPm	268	0	0	268	0	0
41	oilPo	8064	8064	8064	8064	8064	8064
42	rubPr	50420	50420	50420	50420	50420	50420

Decision Variables		S3P1	S3P2	S3P3	S3P4	S3P5	S3P6
43	srpPs	0	0	0	0	0	0
44	oilPt	2671	2671	2671	2671	2671	2671
45	rubPt	0	0	0	0	0	0
46	srpPt	0	0	0	0	0	0
47	tpdPt	2994	2994	2994	2994	2994	2994
48	oilRa	175	175	175	175	175	175
49	rubRa	0	0	0	0	0	0
50	srpRa	0	0	0	0	0	0
51	mgvRm	0	487	487	0	487	487
52	oilRm	0	0	0	0	0	0
53	rubRm	0	0	0	0	0	0
54	srpRm	487	0	0	487	0	0
55	oilRo	12633	12633	12633	12633	12633	12633
56	srpRo	0	0	0	0	0	0
57	rubRr	38685	38685	38685	38685	38685	38685
58	srpRr	0	0	0	0	0	0
59	oilRs	782	782	782	782	782	782
60	rubRs	0	0	0	0	0	0
61	srpRs	0	0	0	0	0	0
62	oilRt	241	241	241	241	241	241
63	rubRt	0	0	0	0	0	0
64	srpRt	0	0	0	0	0	0
65	tpdRt	280	280	280	280	280	280
	sum	**167695**	**167457**	**168703**	**168703**	**167457**	**168703**
1.OCLU in all zones classified by activities (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	0	11844	11844	0	11844	11844
	oilXx	33382	35718	32606	32606	32645	32606
	rubXx	106981	107245	105121	105121	107245	105121
	srpXx	18326	0	6482	18326	3073	6482
	tdpXx	9006	9006	9006	9006	9006	9006
	sum	**167695**	**167457**	**168703**	**168703**	**167457**	**168703**
2. Land use change: Item 1 minus ELU (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	-11844	0	0	-11844	0	0
	oilXx	5218	7554	4442	4442	4481	4442
	rubXx	-2124	-1860	-3984	-3984	-1860	-3984
	srpXx	11142	-7184	-702	11142	-4111	-702
	tdpXx	-2944	-2944	-2944	-2944	-2944	-2944
3. Item 2 in % of ELU	mgrXx	0%					
	mgvXx	-100%	0%	0%	-100%	0%	0%
	oilXx	19%	27%	16%	16%	16%	16%
	rubXx	-2%	-2%	-4%	-4%	-2%	-4%
	srpXx	155%	-100%	-10%	155%	-57%	-10%
	tdpXx	-25%	-25%	-25%	-25%	-25%	-25%

Decision Variables		S3P1	S3P2	S3P3	S3P4	S3P5	S3P6
4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	39	0	39	39	0	39
	srpXm	11844	0	0	11844	0	0
	srpXo	3073	0	3073	3073	3073	3073
	srpXr	2124	0	2124	2124	0	2124
	srpXs	1246	0	1246	1246	0	1246
	srpXt	0	0	0	0	0	0
	sum	**18326**	**0**	**6482**	**18326**	**3073**	**6482**
5. OCLU of shrimp farming in AQZ (rai)	srpAx	11913	0	6482	12921	3073	6482
	srpAs	238	0	1246	1246	0	1246
	srpAx-srpAs	**11675**	**0**	**5236**	**11675**	**3073**	**5236**
6. OCLU correspond with CLDZ [5/] (rai)	srpAx	11913	0	6482	12921	3073	6482
	mgrMx	0	3644	3644	3644	3644	3644
	mgvMm	0	4650	4650	0	4650	4650
	tdpPt	2994	2994	2994	2994	2994	2994
	oilRx	13831	13831	13831	13831	13831	13831
	rubRx=rubRr	38685	38685	38685	38685	38685	38685
7. Benefits (million THB/year	Z1=NPB	1352	276	912	1342	667	912
	Z2=NEB	-369	276	265	-328	271	265
	Z1+Z2	**982**	**552**	**1178**	**1014**	**938**	**1178**

Appendix 6.

Optimal coastal land use (OCLU) options for scenario 4

Decision Variables		S4P1	S4P2	S4P3	S4P4	S4P5	S4P6
1	oilAa	1874	1907	1874	1874	1907	1874
2	rubAa	0	0	0	0	0	0
3	srpAa	33	0	33	33	0	33
4	mgvAm	0	6439	6439	0	6439	6439
5	srpAm	6439	0	0	6439	0	0
6	oilAo	4357	6991	4357	4357	6991	4357
7	srpAo	2634	0	2634	2634	0	2634
8	rubAr	16319	18140	16319	16319	18140	16319
9	srpAr	1821	0	1821	1821	0	1821
10	srpAs	60	0	1068	1068	0	1068
11	srpAt	0	0	0	0	0	0
12	tpdAt	5704	5704	5704	5704	5704	5704
13	mgrMa	0	268	268	268	268	268
14	oilMa	268	0	0	0	0	0
15	rubMa	0	0	0	0	0	0
16	srpMa	0	0	0	0	0	0
17	mgvMm	0	4650	4650	0	4650	4650
18	oilMm	0	0	0	0	0	0
19	rubMm	0	0	0	0	0	0
20	srpMm	4650	0	0	4650	0	0
21	mgrMo	0	476	476	476	476	476
22	oilMo	476	0	0	0	0	0
23	srpMo	0	0	0	0	0	0
24	mgrMr	0	1860	1860	1860	1860	1860
25	rubMr	1860	0	0	0	0	0
26	srpMr	0	0	0	0	0	0
27	mgrMs	0	1008	1008	1008	1008	1008
28	srpMs	1008	0	0	0	0	0
29	mgrMt	0	32	32	32	32	32
30	oilMt	32	0	0	0	0	0
31	rubMt	0	0	0	0	0	0
32	srpMt	0	0	0	0	0	0
33	tpdMt	28	28	28	28	28	28
34	oilPa	2254	2254	2254	2254	2254	2254
35	rubPa	0	0	0	0	0	0
36	srpPa	0	0	0	0	0	0
37	mgvPm	0	268	268	0	268	268
38	oilPm	0	0	0	0	0	0
39	rubPm	0	0	0	0	0	0
40	srpPm	268	0	0	268	0	0
41	oilPo	8064	8064	8064	8064	8064	8064
42	rubPr	50420	50420	50420	50420	50420	50420

Decision Variables		S4P1	S4P2	S4P3	S4P4	S4P5	S4P6
43	srpPs	0	0	0	0	0	0
44	oilPt	2671	2671	2671	2671	2671	2671
45	rubPt	0	0	0	0	0	0
46	srpPt	0	0	0	0	0	0
47	tpdPt	2994	2994	2994	2994	2994	2994
48	oilRa	175	175	175	175	175	175
49	rubRa	0	0	0	0	0	0
50	srpRa	0	0	0	0	0	0
51	mgvRm	0	487	487	0	487	487
52	oilRm	0	0	0	0	0	0
53	rubRm	0	0	0	0	0	0
54	srpRm	487	0	0	487	0	0
55	oilRo	12633	12633	12633	12633	12633	12633
56	srpRo	0	0	0	0	0	0
57	rubRr	38685	38685	38685	38685	38685	38685
58	srpRr	0	0	0	0	0	0
59	oilRs	782	782	782	782	782	782
60	rubRs	0	0	0	0	0	0
61	srpRs	0	0	0	0	0	0
62	oilRt	241	241	241	241	241	241
63	rubRt	0	0	0	0	0	0
64	srpRt	0	0	0	0	0	0
65	tpdRt	280	280	280	280	280	280
	sum	**167517**	**167457**	**168525**	**168525**	**167457**	**168525**
1.OCLU in all zones classified by activities (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	0	11844	11844	0	11844	11844
	oilXx	33827	35718	33051	33051	35718	33051
	rubXx	107284	107245	105424	105424	107245	105424
	srpXx	17400	0	5556	17400	0	5556
	tdpXx	9006	9006	9006	9006	9006	9006
	sum	**167517**	**167457**	**168525**	**168525**	**167457**	**168525**
2. Land use change: Item 1 minus ELU (rai)	mgrXx	0	3644	3644	3644	3644	3644
	mgvXx	-11844	0	0	-11844	0	0
	oilXx	5663	7554	4887	4887	7554	4887
	rubXx	-1821	-1860	-3681	-3681	-1860	-3681
	srpXx	10216	-7184	-1628	10216	-7184	-1628
	tdpXx	-2944	-2944	-2944	-2944	-2944	-2944
3. Item 2 in % of ELU	mgrXx	0%					
	mgvXx	-100%	0%	0%	-100%	0%	0%
	oilXx	20%	27%	17%	17%	27%	17%
	rubXx	-2%	-2%	-3%	-3%	-2%	-3%
	srpXx	142%	-100%	-23%	142%	-100%	-23%
	tdpXx	-25%	-25%	-25%	-25%	-25%	-25%

Decision Variables		S4P1	S4P2	S4P3	S4P4	S4P5	S4P6
4. OCLU of shrimp farming: Reallocation of ELU for shrimp farms (rai)	srpXa	33	0	33	33	0	33
	srpXm	11844	0	0	11844	0	0
	srpXo	2634	0	2634	2634	0	2634
	srpXr	1821	0	1821	1821	0	1821
	srpXs	1068	0	1068	1068	0	1068
	srpXt	0	0	0	0	0	0
	sum	**17400**	**0**	**5556**	**17400**	**0**	**5556**
5. OCLU of shrimp farming in AQZ (rai)	srpAx	10987	0	5556	11995	0	5556
	srpAs	60	0	1068	1068	0	1068
	srpAx-srpAs	**10927**	**0**	**4488**	**10927**	**0**	**4488**
6. OCLU correspond with CLDZ [5/] (rai)	srpAx	10987	0	5556	11995	0	5556
	mgrMx	0	3644	3644	3644	3644	3644
	mgvMm	0	4650	4650	0	4650	4650
	tdpPt	2994	2994	2994	2994	2994	2994
	oilRx	13831	13831	13831	13831	13831	13831
	rubRx=rubRr	38685	38685	38685	38685	38685	38685
7. Benefits (million THB/year	Z1=NPB	1080	276	881	1075	276	881
	Z2=NEB	0	276	276	37	276	276
	Z1+Z2	**1080**	**552**	**1157**	**1112**	**552**	**1157**

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