CHAPTER II

LITERATURE REVIEWS

2.1 SAMUT SONG KHRAM PROVINCE AND DON HOI LORD

2.1.1 Samut Songkhram province

Samut Songkhram province is located in central part of Thailand between latitude 13-14^{o} N and longitude 99-103^{o} E and approximately 74 kilometers from Bangkok. It covers area of 416.707 square kilometers or 260,441.87 rai (Ministry of Interior. 2004) and connects with other province as follows:

North	Ratchaburi province
South	Thai Gulf and Phetchaburi province
East	Samut Sakhon province
West	Ratchaburi and Phetchaburi province

The administration of Samut Songkhram province consists of 3 amphurs, 36 districts, 5 municipalities and 283 villages. Total population is 195,108 persons (51,077 households) contributed from male 93,979 persons and female 101,129 persons (National Economic and Social Development Board, 2005). The majority of Samut Songkhram people hlive in amphur Muang especially Muang Samut Song Khram municipality it closed with Mae Klong river mouth area. In 2003, the gross provincial product (GPP) was 11,158 million baht. The GPP per capita was 57,871 baht (National economic and social development board, 2005). The main careers of people (≈80%) are agriculture, fishery and labor in industry.

Samut Songkhram is generally flat plains with no mountain. There is one main river named Mae Klong River, which run across the province north-south direction through 3 amphurs with around 300 natural and man made canals connected with the main river. Yee Sarn canal, Klong Cone canal, Bangjakreng canal, Bang Klaew canal, Chanuan channel and Maenn Harn canal are the important in this province. In addition, Mae Klong River mouth is located in amphor Muang Samut Songkhram (Thaviongse Sriburi and Nantana Gajaseni, 1996).

Geographical, Samut Songkhram province is divided into 2 parts by Mae Klong River. The Mae Klong estuary runs from the east of river mouth to Samut Sakhon province in distance of 12 km. and the west of river mouth run westward to Phetchaburi province in distance of 11.2 km. In addition, Samut Songkhram coastal line has been changing because of the sedimentation pattern from Mea Klong river. It makes land extending in to the sea.

Coastal area of Samut Songkhram consists of shore line length of 23.2 km. Almost coastal area in the province is characterized as muddy and sandy sediment all of area, it has slope less than 1 % in direction to coastal line. During the low tide, the mudflat will emerge approximately 4 km from shore line into the sea (Thaviongse Sriburi and Nantana Gajaseni, 1996).

The tidal system in Samut Songkhram province is semi–diurnal tide. It consists of high tide and low tide twice times a day. Mean of high tide is +1.23 m. from mean sea level (MLS), mean of low tide is -0.15 m. from mean sea level (MSL) and mean of interval between low and high tide is 1.38 m., however the tidal system has variously effecting from the moon, sea breeze, an air pressure and water current so tidal level must be different in each month.

Land use in Samut Songkhram include fruit orchard (lichee, coconut, pomelo etc.), salt farm, paddy rice, fishery and aquaculture farming. The fishery activities in Samut Songkhram province include fresh water, brackish and marine fishery. In brackish area, there are many types of aquaculture such as shrimp, mud crab, cockle, green mussel and perch fish. In the past, mangrove area was destroyed for aquaculture particularly shrimp aquaculture, causing mangrove area conversion and wastewater discharged to Mae Klong estuary. Now a day, many area of shrimp aquaculture are abandon because the shrimp farmer could not get enough economic benefic.

2.1.2 Don Hoi Lord

Don Hoi Lord (Figure 2.1) is the 1099th Ramsar site located in Mae Klong estuary (13°21’N 099°59’E) in Thailand includes both terrestrial areas and water body of Ban Jakreng, Lam Yai, and Klong Cone district, Muang amphur, Samut Songkhram province covering area of 87,500 ha (Ramsar, 2003).

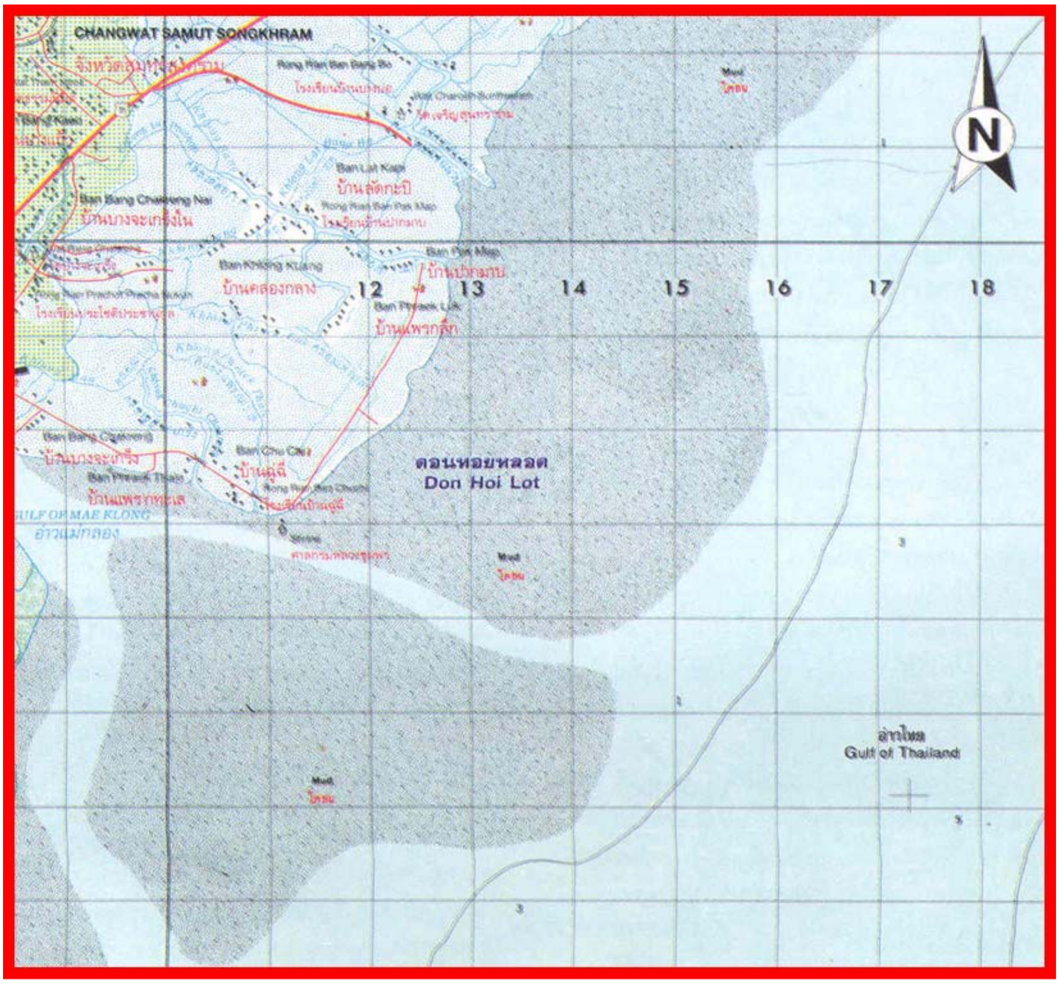


Figure 2.1 Area of Don Hoi Lord, Samut Songkhram province

Don Hoi Lord is a coastal wetland formed by accumulation of sediments and rich in nutrients. It has rare and unique characteristics of natural wetland in Thailand. In addition, the mudflat in wetland is razor calm (*Solen regularis*) habitat.The name of this wetland has been derived from razor clam and it important to local communities economically around Don Hoi Lord.

Don Hoi Lord has high biodiversity Thaviongse Sriburi and Nantana Gajaseni (1996) were found macrofauna including epifauna and infauna of 39 species belonging to 7 phyla of invertebrate and vertebrate following:

Phylum Cnidaria, 3 species

- Jelly fish (*Rhopilema hispidum* and 2 unknown species)

Phylum Nemertinea, 1 species

- Ribbon worm (unknown species)

Phylum Annelida, 4 species

- Clam worm (unknown species)
- Sand worm (unknown species)
- Tube polychaete (unknown species)
- Tube polychate (unknown species)

Phylum Mollusca, 10 species

- Sea snail (*Natical maculosa*)
- Sea snail (*Territella terebra*)
- Sea snail (*Musculus senhauseni*)
- Cockle (*Anadara sp*.)
- Razor clam (*Solen regularis*)
- Rock clam (*Solen vitreus*)
- Bean clam (*Donax faba*)
- Ridge venus clam (*Terpes tergidus*)
- Bivalve (unknown species)

- Bivalve (unknown species)

Phylum Brachiopoda, 1 species

- Tongue shell (*Lingula unguis*)

Phylum Arthropoda, 16 species

- Giant king crab (*Tachypleus gigas*)
- Hermit crab (*Clibanarius infraspinatus*)
- Hermit crab (*Clibanarius longitarsus*)
- Giant tiger prawn (*Penaeus monodon*)
- Banana prawn (*Penaeus merguiensis*)
- Jinga shrimp (*Metapenaeus sp.*)
- Dwarf prawn (*Macrobrachium equiensis*)
- Mantis shrimp (*Cloridopsis scorpio*)
- Mantis shrimp (*Cloridopsis maculata*)
- Pebble crab (*Leucosia haswelli*)
- Eyed swimming crab (*Macropthalmus abbreviatus*)
- Portunid crab (*Charybdis affinis*)
- Blue crab (*Portunus pelegicus*)
- Rock barnacle (*Balanus sp.*)
- Goose neck barnacle (*Lepas sp.*)

Phylum Vertebrata, 4 species

- Conger ell (*Congresox talabon*)
- Flatfish (*Cynoglossus sp.*)
- Goby (*Cryptocentrus sp.*)
- Unknown fish (Unknown species)

Moreover, there are at least 18 species of bird around Don Hoi Lord following:

- Common sandpiper (*Actitis hypoleucos*)
- Edible-nest swiftlet (*Aerodramus fuciphagus*)

- Grey heron (*Ardea cinerea*)
- Javan pond-heron (*Ardeola speciosa*)
- Chinese pond-heron (*Ardeola bacchus*)
- Little heron (*Butorides striatus*)
- Kentish plover (*Charadrius alexandrinus*)
- Little ringed plover (*Charadrius dubius*)
- Whiskered tern (*Chlidonias hybridus*)
- Collared kingfisher (*Halcyon chloris*)
- Brahminy kite (*Haliastur indus*)
- Black-winged stilt (*Himantopus himantopus*)
- Brown-headed gull (*Larus brunnicephalus*)
- Whimbrel (*Numenius phaeopus*)
- Pacific golden plover (*Pluvialis fulva*)
- Wood sandpiper (*Tringa glareola*)
- Marsh sandpiper (*Tringa stagnatilis*)
- Common Redshank (*Tringa totanus*)

Don Hoi Lord is one of the most famous tourist destinations due to distinction of razor clam called “Hoi Lord” in local name, which can be harvested mostly from this sand dune. This bring plenty of tourism to visit there and made more demand of razor clam as delicacy for visitors.

Nowadays, Don Hoi Lord is facing problems because of unsustainable development in term of land development, infrastructure construction. The problems maybe described as follows:

- Changing of environment around Mae Klong river mouth by much more pilling up of sediment.
- Changing of mangrove along coastal zone to aquaculture and decreasing nursing ground and productivity in estuary ecosystem.
- Increasing pollution due to garbage and waste from restaurant and tourism.
- Over harvesting of razor clam regarding high market demand.

2.2 RAZOR CLAM

2.2.1 General characteristics of razor clam

The taxonomic hierarchy of razor clam or Hoi Lord (in Thai) following:

Phylum Mollusca
　Class Bivalvia
　　Order Eulamellibranchia
　　　Family Solenidae
　　　　Genus Solen
　　　　　Species *Solen regularis* Dunker,1862

Razor clam is a bivalve and sex-separate. It has cylinder shape and thin shell hold by hinge teeth. There are 2 openings which anterior opening has two siphons for filter feeding purpose and posterior opening has foot for vertical movement. Adult size of razor clam is ranged from 0.5 cm. to 8.0 cm and lives in sandy soil approximately 1-30 cm. in depth (Department of fishery, 1995).

Figure 2.2 Razor clam (*Solen regularis* Dunker, 1862.)

2.2.2 Distribution of razor clam

Distribution of razor clam normally covers estuary area near river mouth especially in Asia pacific from Japan, Korea, China to Thailand. In Thailand, it is found both at Andaman sea of Phuket and Gulf of Thailand, Songkhla, Prachuap Khiri Khan, Phetchaburi, Samut Songkhram and Samut Prakarn province especially Samut Songkhram province. Don Hoi Lord is located in Samut Songkhram, where it is the largest area of razor clam production in Thailand.

2.2.3 Razor clam feeding behavior

Naturally, razor clam is semi-permanent mud burrower, using foot to dig and bury in the fine sandy soil in vertical direction in their hole. During high tide, razor calm moves up to surface of substrate and protrude siphons into water for pumping water and filtering food from water. Its foods are phytoplankton, zooplankton, organic matters and pieces of decomposed plant or animal. Moreover, when razor clam is attached by enemy or risky sign, razor clam will throw off siphon and move to deeper level in substrate.

2.2.4 Razor clam reproduction

Reproduction of razor clam is external fertilization by male release sperm into water as well as female release egg into water. Sunan Tuaycharoean and Panit Voraingtara (1991) were reported that the release of razor clam gametes is influenced by many factors as the following:

- Stage of gamete development
- Optimum water temperature between 22-39 °C and optimum soil temperature between 21-38 °C
- Optimum salinity between 22-31 ppt

Breeding season of razor clam is twice a year, with the first period starting from June to October and the second period from November to April (Art-Ong Pradatsundarasar et al., 1989). However, breeding season depends on environment condition and might be different from year to year.

2.2.5 Razor clam harvesting methods

Traditionally, there are 5 methods developed by local fishermen knowledge to catch razor clam during low tide when sand dune is exposed. There are as follows:

Method I Dipping lime; this method is the original and traditional method. Local fishermen search for razor clam hole by using fingers to knock on sand dune surface. If a razor clam is near by, it will eject water from siphon thorough the hole then local fishermen has known its location. Consequently, a small bamboo stick dipped in lime is use to poke into the razor clam hole. The razor clam will react and jump up from its hole, and therefore it is caught by fishermen.

Method II Applying lime; local fishermen apply lime on the wet ground where razor clams live around 1 sq.m. Every razor clam in that area will react and jump up from their holes.

Method III Applying lime solution; local fishermen dissolves 1-2 kg of lime in water and apply the solution on the ground more than 2 sq.m. Every razor clam in that area will react and jump up from their holes. This method is similar to method II but it can cover much more area and effectiveness.

Method IV Applying acetylene solution; local fishermen apply acetylene solution on the ground then every razor clam will react and jump up from their holes. This method is similar to method II and Method III but is much more effective. However, acetylene solution has more impact to other species than lime methods.

Method V Digging; this method is the best method for collecting razor clam because no chemicals are involved. However, digging method is unfavorable because it uses more labour and the production is not as high as the other methods.

Figure 2.3 Dipping lime method which is widely used and legalized in razor clam harvesting

Nowadays, local government has allowed local fishermen to uses method I and V to catch razor clam. While method II, III and IV are prohibited because these cause damage to small razor clam and other animals. But some fisherman still try to use those methods due to no serious enforcement.

2.3 OVERVIEWS OF RESEARCH ON RAZOR CLAM AND DON HOI LORD

Art-Ong Pradatsundarasar (1982) studied the influence of sediment on distribution and density of razor clam (*Solen regularis* Dunker, 1862) population in Mae Klong river mouth and reported that razor clam was found in limited area where sediment size is about 0.125 mm and the dune contains almost sand with the least water and organic matter cover during low tide. Average razor clam density was reported 10.20 individual/m^2 .

Department of fishery (1990) studied the effects of lime on razor clam death rate and reported that the increasing death rate was found with razor clam was exposed to lime or used to have some previous lime exposure. It indicated the relationship of lime exposure and razor clam death rate.

Chanintorn Srithongsuk et. al. (1990) also studied the effect of lime on razor clams death rate and reported that lime 0.2 g. per 1 razor clam hole could kill the clam in 72 hrs., while lime 31.2 g per 1 razor clam hole could kill the clam in 48 hrs. In addition, the middle razor clam size (3.1-4.4) had maximum tolerance to lime when compared with other size.

Wanlop Khumsupar et. al. (1991) studied distribution of bloodstock of razor clam around Mae Klong river mouth and found that density of razor clam was 26.88 individual/m^2. Moreover, razor clam has a distribution from the east coast of river mouth to Bang Bor canal mouth.

Somprasong Kanthom and Somchart Sukawong (1991) studied the effect of lime on razor clam death rate and found that small razor clam (1.5-2.9 cm.) has 48 hr.LC_{50} = 376.21 mg/l, large razor clam (4.5-7.0 cm.) has 72 hr.LC_{50} = 234.39 mg/l. In addition, the razor clams were exposed to lime would die faster than the clams that were new exposed.

Sunan Tuaycharoean and Panit Voraingtara (1991) studied breeding biology and environment of razor clam in Bang Bor village, Samut Songkhram province and reported that razor clam is breeding twice a year, during November to April and June to October. The sex ratio was 1:1. Besides, the suitable conditions for razor clam breeding were soil temperature between 21-38 °C, salinity between 22-31 ppt , 25% organic matter composition in soil, pH around 7.85 and Dissolve Oxygen around 5.36 mg/l. Finally, they found that razor clam can breed at size of 42.4 mm.

Kanoksak Jinphuhuad (1994) studied pH of seawater for razor clam and reported that the suitable pH of seawater for razor clam was 6.9-8.5. In addition, if pH of seawater was higher than 9.1, razor clam would die suddenly. On the other hands, if pH of sea water is lower than 6.5, the ability of razor clam feeding would decrease and die from starvation.

Thaviongse Sriburi and Nantana Gajaseni (1996) studied natural resource conservation plan in Don Hoi Lord. It had description that:

Don Hoi Lord is a beautiful wetland and important to Samut Songkhram tourism. Nowadays, Don Hoi Lord has some problems from too much tourists, without waste management, appropriate understanding in relation to aquatic animal habitat or breeding ground and razor and other aquatic animal conservation.

The researches proposed conservation plan for Don Hoi Lord by divide the area into 3 sub-areas, as follows:

1. Preserved area: this area is natural area where high biological value and sensitive to environment change so any human activities are prohibited in this area.

2. Conserved area: this area is peripheral natural area with direct and indirect relationships with natural area. Some human activities are allowed in this area but it will not came environmental change.

3. Developed area: this area allows any human activities but it controlled by government under National Environment Act 1992.

Moreover, low tide in the daytime (April to August) the number of fisherman is more than 260 persons/day. On the other hand, low tide during in the nighttime start from October to January some fishermen illegally use applying lime solution method to catch razor clam. It is more damage to razor clam population than ordinary method and cause decreasing population.

. Rangsimant Boutong (1997) studied the relationship between plankton population and breeding season of razor shell genus *Solen* at Don Hoi Lord, Samut Songkhram province and reported that most food in razor clam stomach content was phytoplankton. In addition, densities of phytoplankton and zooplankton were not related to density and breeding season of razor clam population.

Ruffolo et al. (1999) studied the population dynamics of razor clam at Don Hoi Lord and reported that razor clam has a growth rate at 1 cm/month, furthermore population of razor clam was decreased from 49.5 individual/m^2 in 1994 to 4.1 individual/m^2 in 1997. In addition, most collected clam in the study has size between 2 to 4 cm. In 1998, they could not catch razor clam size bigger than 7 cm. Finally, they concluded that the decrease of razor clam population might be caused by inappropriate harvesting method.

Natsucha Oiamsomboon (2000) studied the people opinion on Don Hoi Lord conservation at amphur Muang, Samut Songkhram province and reported that most people agreed with Don Hoi Lord conservation. Because they realized that Don Hoi Lord is an important place to Samut Songkhram province in terms of the legend and tourism. Moreover, they were glad to cooperate with the government in Don Hoi Lord conservation activities.

Weerasak Jarinrattanakorn (2001) studied the media exposure, awareness and participation in razor clam conservation among people in amphur Muang, Samut Songkhram province and reported that high level of media exposure in razor clam conservation and awareness in razor clam conservation. On the other hand, the participation of people in razor clam conservation is in the medium level.

Wanpen Sriprathumwong, Ritthikorn Sornkaew and Nopadol Phuwapanish (2002) cultured razor clam from fertilization egg 860,000 eggs from 3 kg. of broodstock in man made nursery. The survival rate was 0.70 % when razor clam developed in juvenile stage of 520x1,040 micron and 0.03% when razor clam reached adult stage (1.5-3 cm.).

Nathakan Suwanna (2003) studied the ability of community to manage local resources: a case study of Don Hoi Lord, Samut Songkhram province and reported that the social, economic and politic developments affected on the decrease of razor clam population because of increasing razor clam demand. The high market demand made local fisherman search for another method to catch more razor clam than old method, without realizing its effect on the environment. When the government established the regulation to control razor clam harvesting, there is a lot of cooperation in Don Hoi Lord conservation. The protected area for razor clam has been established and local fishermen also participate in conservation activities. The activities for conservation in community also reduced inappropriate harvesting method in local fishermen and set up conservation group.

2.4 ECOLOGICAL MODELLING

Few decades ago, there is one science has been developing from many scientific disciplinary (eg. Ecology, Mathematic, Computer science, etc.) that integrated in terms of subsystem into main system. That calls "Modelling approach" which has main objectives are:

- To know and understand system dynamics
- To know system mechanisms
- To know even or trend of system in the future

Combining ecological knowledge with modelling approach has give rise to "Ecological modelling". It is an effective tool to study ecosystem and ecosystem management (Jackson et al., 2000). The approach focuses on modelling subsystem of an ecosystem as well as ecological relationships within and between the subsystems.

The process of modelling uses subsystem data that considers the main system from past until present. Correction of the model and result depend on quality of data from each subsystem that contribute to the model.

There are 3 main processes to build an ecological modelling:

1. Model construction: the model will be construct from conceptual model combining with quantitative model (or mathematical model)

2. Model calibration: this process tests the model by performing simulation runs for accuracy, consistency of model in several time steps.
3. Validation: this process compares the results of model by runing simulation under various scenarios with the real world or system study.

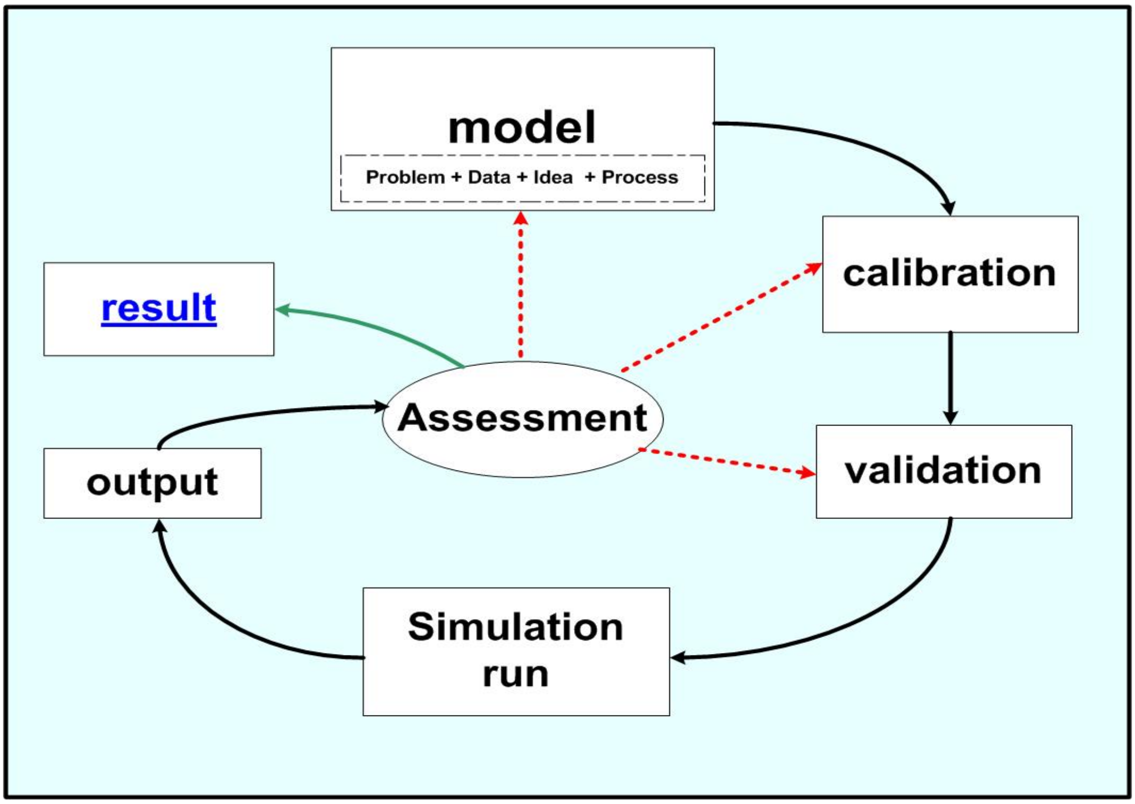


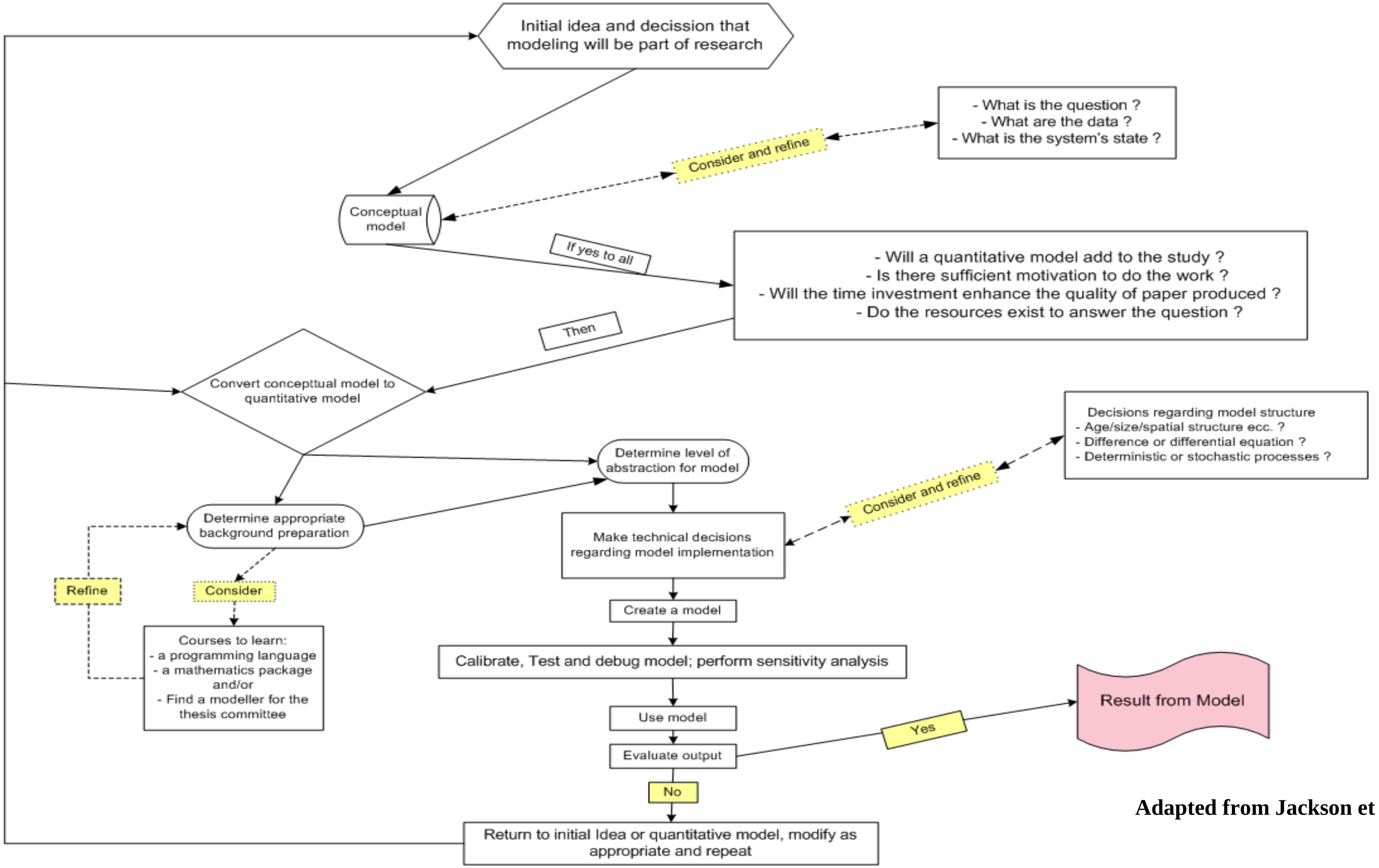
Figure 2.4 Overview of modelling approach

However, modelling approach is a computer-based tool, especially with simulation runs on computer program. The computer hardware and software make modelling approach more applicable to various fields of study for instance, economic, marketing, engineering and science.

Nowadays, there are many environmental problems that have been occurring in the world. Modelling approach is an effective tool to explore and find solutions for the present problems or some problems which may happen in the future.

2.4.1 Methodology to build an ecological model

Modelling approach is a tool to study system dynamic and/or relationships in the system. Fast computers and graphical software package have removed much of the drudgery of creating model with a programming language and opened new avenues of model construction, use and even misuse. In addition, models provide an opportunity to explore ideas regarding ecological systems that it may not be possible to field-test for logistical, political and/or financial reasons (Jackson et al, 2000). The methodology to build ecological models, shown in figure 2.5, summarizes the process of creating an ecological simulation model. The model construction processes start when a researcher makes decision to use model in research. To transfer current knowledge into a conceptual model is the first step. Then, the quantitative models are considered to combine with conceptual model and the simulation model is constructed from those under computer software or computer language. Calibration, test, debug and sensitivity analysis are important processes to validate the model because they can improve and make model correctly and relate with the real world. Finally, evaluation of output from model is important to determine the value of the constructed model and to allow the researchers to know their mistakes and correct them.



Adapted from Jackson et al., 2000

Figure 2.5 Methodology to build an ecological model

2.5 COMPANION MODELLING

Models have been known to represent the system structure and dynamics in a simplified form to enhance the understanding of complex systems. New modelling approaches are needed to effectively identify, generate and relate information for better understanding of the system. It is also needed to make shared knowledge to guide management decisions (Costanza and Ruth, 1998).

The sharing of knowledge to guide management decision and modelling process should be performed together to make maximum use in modelling approach. Companion modelling approach is a one of modelling approach which is composed of modelling process and share knowledge in field of renewable resource management.

2.5.1 Companion modelling:The charter

As Barreteau et al. (2003) the companion modelling approach to be used with two following aims:

- Learning on systems or support collective decision processes in these systems.
- Increasing knowledge for either the scientist or the field actor, through an interaction between them mediated by an evolutionary model.

Companion modelling is deals with a combination of pragmatic and theoretical questions regarding the management of renewable resources and environment, and is facing to complex and very dynamic research objects. Such a context leads to realization of importance of uncertainty and the existence of multiple and legitimate points of view, including the ones producing scientific expertise. These different view points deserve to be taken into account in an iterative process of understanding, confrontation and analysis. Therefore, companion modelling approach has processed in the same tendency:

- The fate of all the assumptions backing the modelling work is to be discarded after each interaction with the field, that is to say to be voluntarily and directly subject to refutation.
- Having no a priori implicit experimental hypothesis is an objective implying the adoption of procedures to unveil such implicit hypotheses.
- The impact in the field has to be taken into consideration as soon as the first step of the approach, in term of research objective, quality of approach, quantified monitoring and evaluation indicators.
- Particular attention should be given to the process of validation of such a research approach, knowing that a general theory of model validation does not exist and that procedures differing from those used in the case of physical, biological and mathematical models need to be considered.

Tools in companion modelling can accompany the collective decision-making dynamics and make stakeholders understand the system of study. For example Multi-agent systems (MAS), Role-playing game (RPG), Geographic information system (GIS), economic tools, etc. can be tools in companion modelling approach. The tool selection to using in companion modelling is depending on the situation in various systems. Thus, the production of knowledge or point of view on a given system could lead to:

- improved knowledge of actors and/or decision-makers
- facilitated dialogue among stakeholders (including experts) providing a frame work for discussion and sharing of information, an exchange of viewpoints, knowledge and beliefs among them.
- negotiated support system aiming at closing the gap between diverging point of view and conflicting situation in system study.

From concepts of modelling and companion modelling approach, stakeholders learn collectively by creating, modifying and observing simulations. When carrying out simulations, one acts on the decision-making process by creating or modifying representations. Companion modelling leads stakeholders to share representation and simulations, taking into account possible decisions and actions related to their environments which are under consideration (management rules, new infrastructure etc.) Meanwhile, companion modelling does not include the other possible steps of the mediation process dealing with a more quantified expertise (size of a new infrastructure, estimated production etc.). Companion modelling intervenes upstream of the technical decision to support the reflexion of concerned actors, in order to produce a share representation of the problematic and to identify possible ways toward a process of collective management of the problem.

With regard to the two aims in companion modelling approach above, the first type of usage looks for its scientific legitimacy in the production and relevance of knowledge, while the latter aims to improve the quality of collective decision-making processes. In both aims, there is production of knowledge through the interaction among researchers and local stakeholders. But in the first situation, this production of knowledge (being for researchers, or for local actors through training activities) is the objective, while in the second aim is a necessary element of the method to achieve the main objective of supporting collective decision. However, there is nothing can guarantee that the tools and/or the models tested in a given situation will be useful, efficient and can adapted in another situation because the dynamics and the interaction in each system are different. That why the companion modelling approach has 2 aims and these concerning together, in addition the knowledge produced by each of two aims are useful to elucidate the secondary effects created by one of them.

2.5.2 Multi-agent systems modelling and role-playing game

Recently, several researchers started to use multi-agent systems, also called agent-based modelling (ABM), in different fields. Researchers in ecology or economics use this methodology and associated tools for ecosystem management. If a history of multi-agent systems were to be written over the coming year, those authors would certainly situate the birth of this approach and its formative years in the rich breeding ground of the interdisciplinary movement. Originally, multi-agent systems came from the field of artificial intelligence (AI). At first, this field was called distributed artificial intelligence (DAI); instead of reproducing the knowledge and reasoning of several heterogeneous agents that need to coordinate to jointly solve planning problems. (Bousquet and Le page, 2004)

Multi-agent systems are an assembly of agents with specific goals capable of perceiving, communicating, interacting and acting in an environment with other agents (Ferber, 1999). On the other hand, Le Page et al. (2000) propose that multi-agent systems are made of collection of agents, an agent being a computerized autonomous entity that is able to act locally in response to stimuli from the environment or communication with other agents (figure 2.6).

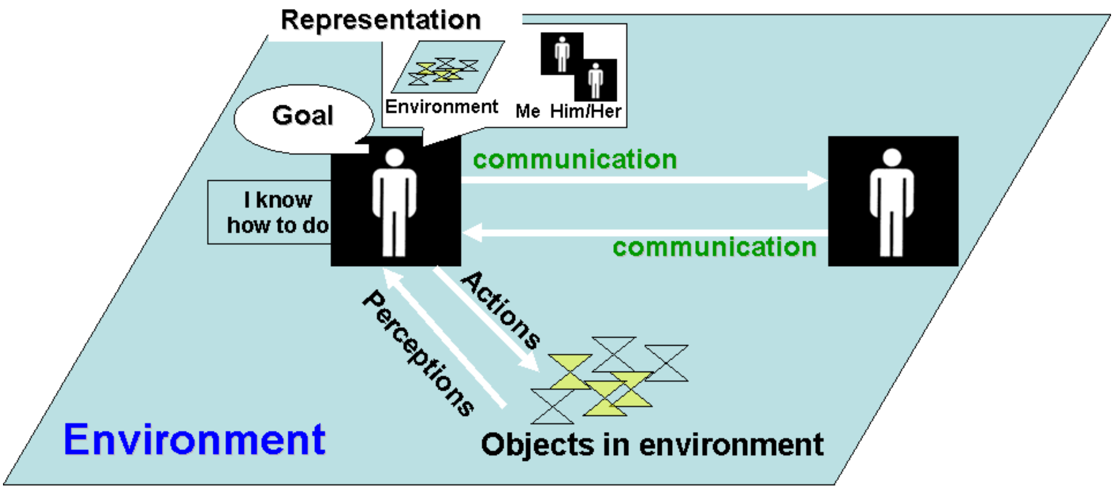


Figure 2.6 Multi-agent systems general organization and principles.
(adapted from Ferber, 1999)

Agents have:

- internal data representations (memory or stage)
- means for modifying their internal data representations (perception)
- means for modifying their environment (behaviors)

The key concept of MAS concerns the interactions between agents. These interactions may occur through the environment, either by being at the same place at the same time or less directly (for instance by ownership, resource depletion, pheromone depletion), or may occur explicitly, either via direct communication (exchange of messages) or via transactions (e.g., financial). (Le Page et al., 2000)

MAS provides simulation methods rich in potentials capable of modelling interactive processes between social and ecological dynamics (Bousquet et al., 1999). Following to Ferber (1999), the main qualities of multi-agent modelling are its capacity for integration and its flexibility. It is in fact possible to integrate within the same model quantitative variables, differential equations and behaviors based on symbolic rule. It is also very easy to integrate modifications, each enhancement of the model being brought about by adding behavioral rules which operate at the individual level. In addition, multi-agent systems make it possible to model complex situations whose overall structure emerge from interactions between individuals, that is, to cause structures on the macro level to emerge from models on the micro level, thus breaking the level which is so flagrant in classical modelling. The data gathered to build the model may came from real observations (numerical values) or knowledge (a more subjective point of view on the system) and are usually formalized using formal semantics or mathematical logic to reduce ambiguities as much as possible (Drogoul, Vanbergue and Meurisse, 2002).

For better understanding and modelling of the decision-making process and for better management of natural and renewable resources, MAS and Role-playing (RPG) game are combined in companion modelling approach. The several potential parallels between role game and MAS listed in Table 2.1

Table 2.1 Correspondences table between role-playing game and MAS (Gurang, 2004)

Role-playing game	Multi-agent systems
- Players	- Agents
- Roles	- Rules
- Game set	- Interface
- Game session	- Simulation
- Turn	- Time step

There are a few experiences with the coupled use of models and role games foe ecosystem management. Fish banks game, developed in 1993 (Meadows and Meadows, 1993 cited in Bousquet et al., 2002). It is a famous role game which is used for educational purposes. Human players play the role of fish companies that share a common resource. A simulation model simulates the dynamics of fish resource that the human plays harvest. The objective of the Fish Banks game is to illustrate and teach the tragedy of the commons principle: free access to resources leads to biological depletion and consequently to economic overexploitation.

Closely articulated with MAS models in the companion modelling approach, role-playing game are used to produce new knowledge, to help build MAS models, and to validate them (Figure 2.7). Depending on the circumstances, the linkage between two tools can very (Aquino et al., 2002 cited in Trebuil et al.,2002)

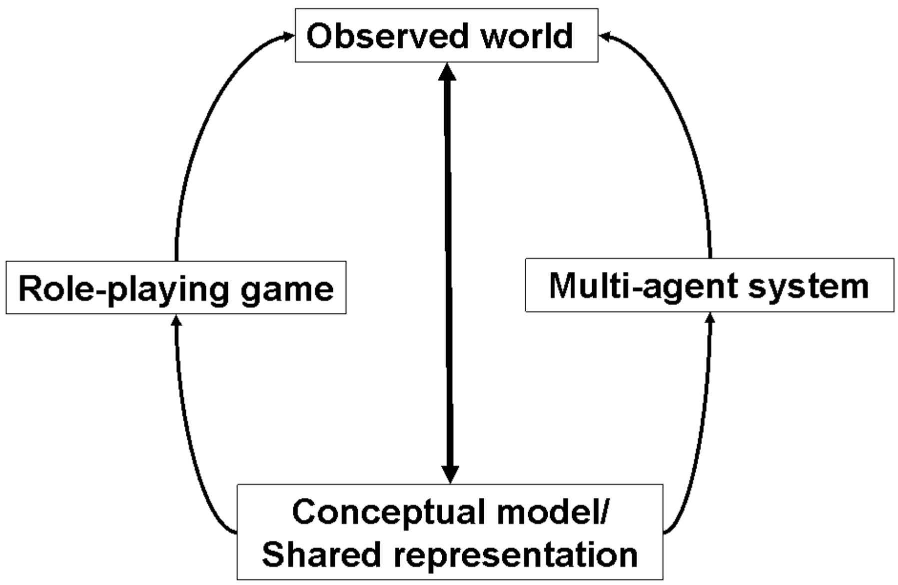


Figure 2.7 Linkages between the reality and interactive tools in the companion modelling approach (adapted from Trebuil et al., 2002)

The use of role-playing games derived from more complex models through simplifications facilitates the communication of the results of agent-based computer simulation to stakeholders. It helps empower them to use such powerful tools when looking for "solution" to concrete natural resource management (Trebuil et al., 2002).

Cormas (**Co**mmon-pool **R**esources and **M**ulti-**a**gent **S**ystems) has been develop since 1995. It provide facilities to build analyze agent-based models that represent ecosystems where various human activities compete for the use of natural resources (Le Page and Bommel, 2004). Cormas is based on the software VisualWorks which, in turn, is a programming environment based on Smalltalk language. Cincom, the American company that market VisualWorks, distributes the software freely (for education and research purposes) Cormas is also available to the scientific communities at http://cormas.cirad.fr/indexeng.htm . However, the goal of Cormas is not to make accurate predictions about the behavior of complex systems but to provide framework to help people develop new ways of thinking (Gurung, 2004).

There have been some researches on natural resource management using MAS and/or RPG as tools in study:

Bousquet, Cambier and Morand (1994) were build fishery model case of the central delta of the Niger river and tired to contribute the multidisciplinary knowledge from the model.

Barreteau and Bousquet (2000) studied the viability of irrigated systems in Senegal River Valley. RPG and MAS were conducted to explore viability of irrigated system in social network, it well knows in SHADOC model.

Bousquet et al. (2001) studied simulation for hunting wild meat in a village in eastern Cameroon using Cormas and reported that a hunting behavior can affected population and age structure of blue duiker it is a meat for local villager

Trébuil et al. (2002) conducted companion modelling approach for watershed management in northern part of Thailand, focusing on steep-land management by limiting land degradation in rapidly diversifying and market-integrated farming system of Akha village. This approach helped to identify acceptable rules for an improve regulation of collective uses of land resources.

Mathevet et al. (2003) studied interactions between duck population and farming decision for agriculture or leasing of hunting rights in the Camargue (Southern France) by using Cormas. There were 3 scenarios in this study: Scenario A: “high rice-crop profitability”, Scenario B: ”critical period for the agricultural market” and “Scenario alternation”. The results from each scenario showed that in Scenario A population of duck will be increased to more than 120,000 individuals this number more than duck population in scenario B about 2 folds and in term of land use agricultural land quickly increased to cover nearly 80% of the region but in Scenario B the natural land has develop to cover 55% of the region because of the increased of hunting marshes. For “Scenario alternation” whatever in order ABABAB or BABABA

Suphanchaimart et al. (2003) use MAS studied farmer decision making in enlarge area for growing sugar cane in North of Northeastern in Thailand. The results contributed to more understanding how farmers make a decision to use their land to grow a type of agricultural product

Gurung (2004) used multi-agent systems and role-playing game to study irrigation system in cased of water sharing in Lingmuteychu watershed, Bhutan and reported that those tools in the study can improve stakeholders in watershed shared their perception and helped collective decision to managing their water resource.