CHAPTER SIX

Integrative EcoHealth/One Health Approach for Sustainable Liver Fluke Control: The Lawa Model

Sirikachorn Tangkawattana[*,¶] **and Banchob Sripa**[§,¶,1]
[*]Faculty of Veterinary Medicine, Khon Kaen University, Khon Kaen, Thailand
[§]Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand
[¶]WHO Collaborating Centre for Research and Control of Opisthorchiasis (Southeast Asian liver fluke disease); Tropical Disease Research Center, Khon Kaen University, Khon Kaen, Thailand
[1]Corresponding author: E-mail: banchob@kku.ac.th

Contents

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Abstract

The Lawa model is a successful integrative and sustainable means of controlling opisthorchiasis in Thailand. The model integrates the EcoHealth and One Health holistic approaches with systems thinking to target the interruption of *Opisthorchis viverrini* transmission. Using the six principles of EcoHealth and emphasizing the three domains of One Health (human—animal—ecosystem), the program targets each step of the parasite life cycle, thus maximizing the chances of interrupting the life cycle of the parasite. The main drivers of success are the village health volunteers and health-promoting hospitals, together with the support of the government and academia. The success of the model has led to continuous expansion, adoption nationally and internationally and application to the control of other neglected tropical diseases as well as noncommunicable diseases.

1. INTRODUCTION

The Lawa model is a successful integrative and sustainable program to control opisthorchiasis, which is caused by infection with the liver fluke, *Opisthorchis viverrini*. Over the past 10 years, the program has essentially eliminated new cases of infection in the Lawa Lake region in Thailand (Sripa et al., 2015). Opisthorchiasis was a major public health problem in this country for decades, but the magnitude of the disease prevalence has been gradually reduced in parts of Thailand. The International Agency for Research on Cancer (IARC, 1994) has classified the liver fluke as a Group I biological carcinogen that causes fatal bile duct cancer or cholangiocarcinoma. Southeast Asian countries, particularly in the Greater Mekong Subregion, where the disease is endemic include Lao PDR, Cambodia and the central and southern parts of Vietnam and Thailand. Endemic areas usually have the common geographical characteristic of being wetlands.

In Thailand, the first national survey during 1980–81 revealed an overall prevalence of 14% with the highest prevalence in the northeast (34.6%) part of the country. In 2000 and 2009, the average prevalence declined to 9.4% and 8.7%, respectively (Jongsuksuntigul and Imsomboon, 2003; Sithithaworn et al., 2012). Recently, a nationwide survey in 2014 showed a prevalence of *O. viverrini* of 5.1%. However, over 3.5 million people were still infected, mostly in the eastern part of northeast Thailand (Suwannatrai et al., 2018).

In Thailand, most of liver fluke control campaigns implemented nationwide are focussed on changing eating behaviour, such as campaigns discouraging the eating of raw fish, which started in 1987. However, this approach is not holistic and lacks active community participation as well as continuity and sustainability. After the campaign stopped, the reinfection rate was very high in endemic areas (Upatham et al., 1988). This top-down policy wastes valuable resources and funds. Sripa et al. (2015) published a new control strategy that combined a holistic approach and systems thinking called the 'Lawa model'. Sripa et al. analyzed the failure of opisthorchiasis control in the past and identified the research gaps that allowed for development of a new control idea. A primary characteristic of this new integrative control approach is an understanding of the nature of the disease, particularly the transmission of the parasite. This kind of holistic assessment of the problem, which also implements the EcoHealth (EH) and One Health (OH) concepts and is also linked to local policies and culture, has been effectively implemented in the form of the Lawa model for over 10 years.

Sripa et al. (2015) described that the Lawa model is an innovative research-based strategy for integrative liver fluke control using the EH/OH concept. In development since 2007, the '*Lawa Project*' has filled gaps in knowledge in the transmission dynamics of the liver fluke. The Lawa project originated from this idea and was further refined and renamed the 'Lawa model'. The name comes from Lawa Lake or Lawa village, a liver fluke endemic area in Khon Kaen province. The villages around the lake, including Lawa village, are located in a wetland comprising three lakes (Kaeng Lawa, Nong Kong Kaew and Kud Kao) along the Chi River. There are 13 villages around Lawa Lake where people practice agriculture in a rural lifestyle (Sripa et al., 2015). In the past, the villages in this area have a high prevalence of *O. viverrini* infection compared with other villages in Khon Kaen Province.

The lessons from unsuccessful control in the past suggest that the problem required new thinking for a more effective solution. Because the life cycle of the liver fluke requires intermediate hosts and a reservoir host to fulfil the life cycle, it is not surprising that this area is endemic for the disease. To gain an understanding of the nature of the disease and the dynamics of transmission, it was necessary to investigate the ecosystem of Lawa Lake, including the intermediate and reservoir hosts of the parasite. The lessons from the past showed that focussing on human control only is insufficient in elimination of the disease.

2. SYSTEMS THINKING AND THE ECOHEALTH/ONE HEALTH CONCEPT

Changing human behaviour is difficult even when that change will improve health because the potential benefits are not immediate. Systems thinking can create a deeper understanding of human behaviour and of the nature of opisthorchiasis as well as provide a new approach to problem solving. The conclusions from lessons learnt from failures in the past are that there are six main obstacles. They are (1) the culture and behaviours that are vulnerable to liver fluke infection such as fishing, food preparation and sharing, and consumption of raw fish; (2) a wetland ecosystem that is conducive to the growth of the parasite and its transmission to the hosts; (3) the efficacy of the parasite in replication and transmission; (4) communicating awareness to the community of the complicated pathological consequences and treatment; (5) historically unprecedented environmental changes, especially water resources; and (6) the lack of continuity in government policy and control activities. From these obstacles, the research team led by Dr. Banchob Sripa from the Tropical Disease Research Center of Khon Kaen University (TDRC-KKU) developed the original idea from a common sense strategy based on the nature of the infection and the linkage to sociocultural factors. This new strategy has and should continue to overcome the obstacles from the past (Sripa et al., 2017).

Based on WHO systems thinking (de Savigny and Taghreed, 2009), the Lawa model was introduced to Southeast Asian countries (SEA) in the late 2000s (Nguyen-Viet et al., 2015) (Table 1). In the beginning, the Lawa project integrated the three pillars of EH (transdisciplinarity, participation and equity) to the original idea of OH, which had already been introduced to Thailand. The nature of the life cycle of the *O. viverrini* parasite, involving a human and animal host and the environment, is consistent with the concept of OH and the Lawa model. Integrating holistic approaches by targeting the parasite life cycle also follows the 10 steps of systems thinking (Fig. 1).

Table 1 Analysis of Lawa Model Activities in Controlling Opisthorchiasis Based on the 10 Steps of Systems Thinking for Health Systems

Systems Thinking Steps	Description	Activities in Lawa Model
I. Intervention Design		
1. Convene stakeholders	Assemble stakeholders from across the health system, plus selected intervention designers and implementers, users of the health system, and representatives of the research community	Define all key stakeholders Stakeholder meetings at different levels Report current situation of problem (opisthorchiasis)
2. Collectively brainstorm	Collectively brainstorm on possible system-wide effects of the proposed intervention, respecting systems characteristics and dynamics	Brainstorm during stakeholder meeting to find solution together
3. Conceptualize effects	Conceptualize effects to map how the intervention will affect health and the health system	Plan the intervention and conceptualize effects
4. Adapt and redesign	Adapt and redesign to optimize synergies and minimize any negative effects	Monitor and evaluate the intervention and project; adjust the plan
II. Evaluation Design		
5. Determine indicators	Determine indicators that are important to track in the redesigned intervention	Define the indicator (such as prevalence, number of people consuming raw fish, cure rate, etc.)
6. Choose methods	Choose methods to best track the indicators	Select the methods and prioritize
7. Select design	Select evaluation design that best manages the methods and fits the nature of the intervention	Select the evaluation method (such as prevalence in all hosts)
8. Develop plan and timeline	Develop a plan and timeline by engaging the necessary disciplines	Develop plan and timeline for working
9. Set budget	Set a budget by considering implications for both the intervention and the evaluation partnership	Budgets are from different grant agencies local, national and international
10. Source funding	Source funding to support the evaluation before the intervention begins	Include in No. 9

Adapted from de Savigny, D., Taghreed, A., 2009. Alliance for Health Policy and Systems Research, World Health Organization. Systems Thinking for Health Systems Strengthening. http://apps.who.int/iris/bitstream/10665/44204/1/9789241563895_eng.pdf?ua=1.

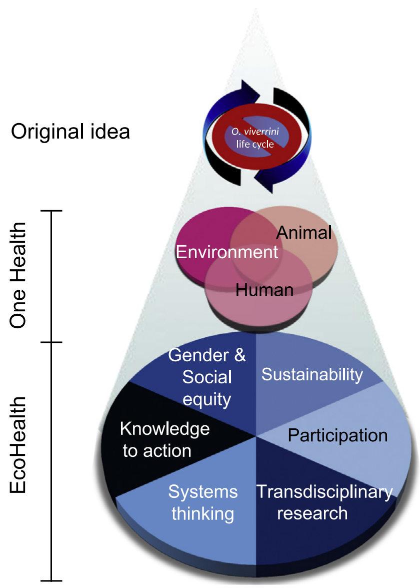

Figure 1 Systems thinking of the Lawa model that integrates EcoHealth/One Health approach to target interruption of *O. viverrini* transmission.

2.1 Principle of EcoHealth/One Health

2.1.1 Three Pillars and Six Principles of EcoHealth

The EH approach focusses above all on the place of human beings within their environment. This includes unavoidable links between humans and their biophysical, social and economic environments that are related to health (IDRC, 2010). In the beginning of the Lawa project, the three pillars of EH later was changed to six pillars. The three pillars consisted of transdisciplinarity, participation and equity (Lebel, 2003). Systems thinking, sustainability, gender and social equity and turning knowledge into action were added later by the International Development Research Centre (Charron, 2012). The application of the pillars on EH is currently in the Lawa model.

2.1.2 Three Domains of One Health

One Health is the collaborative effort of multiple disciplines and sectors—working locally, nationally and globally to attain optimal health for people, animals and the environment (AVMA, 2008; Frank, 2008). OH was introduced by USAID (United States Agency for International Development), WHO (World Health Organization), FAO (Food and Agriculture Organization) and OIE (World Organization for Animal Health) with an emphasis on network building more than research or intervention projects for emerging infectious diseases (Nguyen-Viet et al., 2015). The concept of OH that has been accepted worldwide is the convergence and interconnection of the human, animal and environment domains. The ultimate goal of OH is to reach optimal health. This requires an integrated, holistic approach for a better understanding of the health issues/problems converging on the human–animal–environment domains (AVMA, 2008). The original idea of the Lawa model that focuses on interruption of the parasite transmission is related to these three domains of OH, which were integrated into the model. The activities are listed in Table 2.

2.1.3 Integration of EcoHealth/One Health to the Lawa Model

Although EH and OH have a different origin, they have common concepts. EH/OH are similar in that they (1) are motivated by health concerns about human–animal issues within the socioecosystem, (2) integrate different disciplines, and (3) aim to mitigate the risks that threaten the ecosystem (Roger et al., 2016). For the original idea of interrupting liver fluke transmission, EH/OH is an appropriate approach to tackle the disease. Interrupting *O. viverrini* transmission, with a focus on human–animal–environment health and with work based on the six EH pillars, is innovative systems thinking applied to the Lawa model (Fig. 1).

2.2 Interruption of the *Opisthorchis viverrini* Life Cycle

Targeting the parasite life cycle was initiated after treatment alone was unsuccessful in reducing the prevalence of infection. Understanding the nature of infectious agents supports identification of key points and actors (Sripa et al., 2017). After the liver fluke's eggs are shed to the environment from the definitive host via defecation, the fluke requires two intermediate hosts to develop for the next step. The first intermediate host is the *Bithynia* snail. In the snail, the miracidia of parasite develop into sporocyst, redia and cercaria. Then the free-living cercariae swim and encyst in the skin, fins and flesh of the second intermediate host, the cyprinoid or cyprinid fish. The cysts then transform into metacercariae in the fish and are ingested by a definitive host such as humans and fish-eating mammals such as dogs and cats (Fig. 2). According to the OH approach, the Lawa model targets each step of transmission, which is summarized in Table 2 (modified from Fig. 2 in Sripa et al., 2017).

Table 2 Activities, Aims and Stakeholders Classified by Using OH Concept

OH Domains	Activities	Aims	Stakeholders
Human	Stool examination	Survey infection status	Physicians, health officers, village health volunteers, teachers, the local governor, Buddhist monks
	Praziquantel (PZQ) treatment in infected individual	Destroy the fluke and stop the egg contamination to environment	
Human/ Environment	Latrine installation in every household	Prevent egg contaminating to environment	
	Human waste management		
	Health education	Change behaviour	
Environment	Lake shore renovation (>1 m in depth)	Prevent increase in snail population	Engineers
	Water quality analysis	Monitoring and surveillance	Ecologists, biologist
Environment/ Animal	Digging the lake shore 1 m in depth	Prevent the growth and replication of *Bithynia* snail	Malacologists, ecologists, engineers
Environment/ Animal Intermediate host—*Bithynia* snail	Snail/fish examination for parasite	Monitor and surveillance	Malacologists, ecologists
Animal Intermediate host—cyprinoid fish	Recipes for a safe cooked fish dish	Food safety	Fish biologists, food technologists or restaurant owners
Animal Reservoir host (cats and dogs)	Stool examination and PZQ treatment	Prevent parasite egg transmission	Veterinarians, government
	Animal population control, i.e., feral animals	Issue local regulations for controlling	
Human	Policy making	Sustainable control by policy	Local governor, national governor

Summarized from Sripa, B., Tangkawattana, S., Sangnikul, T., 2017. The Lawa model: a sustainable, integrated opisthorchiasis control program using the EcoHealth approach in the Lawa Lake region of Thailand. Parasitol. Int. 66, 346–354.

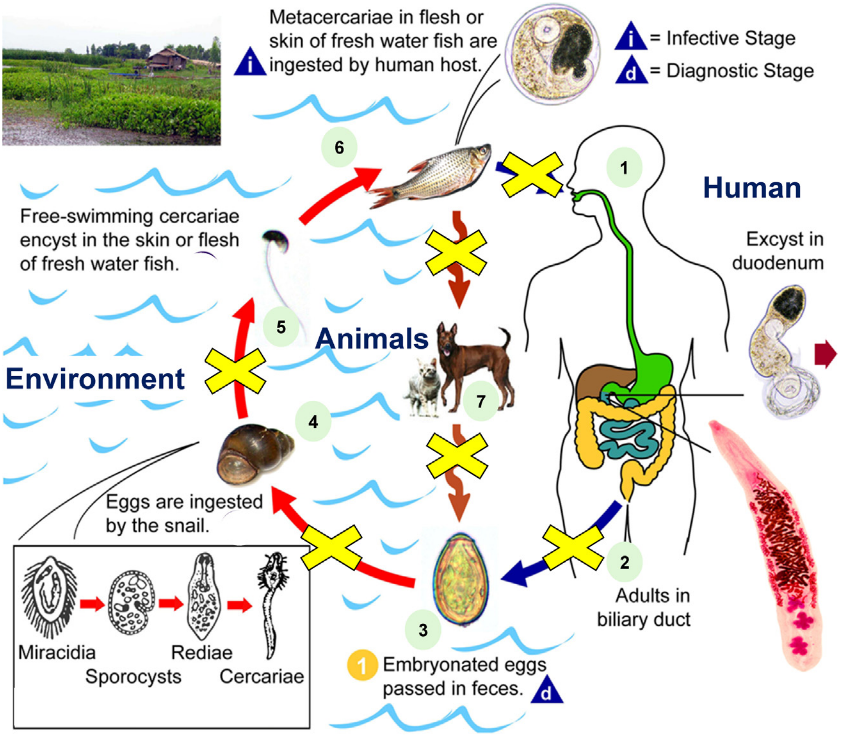

Figure 2 Integrated control of Lawa model targeting on *O. viverrini* life cycle. *Adapted from Sripa, B., Tangkawattana, S., Sangnikul, T., 2017. The Lawa model: a sustainable, integrated opisthorchiasis control program using the EcoHealth approach in the Lawa Lake region of Thailand. Parasitol. Int. 66, 346–354.*

2.3 From Top-Down to Bottom-Up

Lessons learnt from unsuccessful opisthorchiasis control in Thailand over the past 30 years indicated that the '*top-down*' policy of medical and public health control failed to solve this chronic problem. Interventions, such as parasitic treatment, sanitation improvement and health education, without understanding the sociocultural factors and ecosystem were not efficacious or sustainable and resulted in only brief declines in the prevalence of infection (Sripa et al., 2015). The holistic approach, which involves community participation, is '*bottom-up*' and thus provides more information to understand the local problem in depth. In general, the '*top-down*' policy starts from a large basic unit, originated and directed by the government, the highest rank. Alternately, the '*bottom-up*' policy is built up from details or ideas at the grass root level. Integrating both the '*top-down*' and '*bottom-up*' policies results in a more effective and sustainable control, as seen with the Lawa model. From the community level, the Lawa model has stimulated stakeholders to understand the nature of the disease.

3. HUMAN HOST

3.1 Keys to Success

3.1.1 Stakeholder Engagement and Community Participation

Community involvement is a prerequisite for sustainability of the Lawa model. Activities (such as stakeholder meetings, group discussion and interviews.) elicit the attitudes, knowledge and opinion of people in the community. According to the typology of participation by Pretty et al. (1995), community participation falls under '*functional participation*' (formation of groups to meet predetermined objectives related to the project) and expands to '*interactive participation*' (that leads to action plans and the formation of new local institutions or the strengthening of existing ones). The health-promoting hospitals (HPHs) and village health volunteers (VHVs) are the lead group who are actively involved and initiate activities for reducing the prevalence of liver fluke infection and cholangiocarcinoma.

Stakeholder engagement in the Lawa model is one of the most important aspects of community participation. Stakeholders are defined by how their involvement in disease control relates to each step of the parasite life cycle (Fig. 2). Most stakeholders are from the affected communities around Lawa Lake. Those communities are the '*primary stakeholders*'. Local authorities such as the local governor (Subdistrict Administrative Organization [SAO]) are '*secondary stakeholders*'. In the initial step, the key actors were defined by their involvement in disease transmission and control. Most were active actors from different disciplines and sectors in the community, such as health officers, educational staff, veterinarians, monks, community leaders and the local governor.

A useful tool to obtain and gather information from these actors, who are key sources of information on disease transmission, is participatory epidemiology (PE). PE relies on the techniques of participatory rural appraisal, qualitative epidemiology and surveys. Based on the use of participatory techniques, participatory epidemiology has been used to harvest qualitative information and intelligence from the community (Schwabe, 1984). PE was

Figure 3 Participatory epidemiology obtains qualitative information from the Lawa community.

introduced and applied to gain local information and wisdom from the villagers (Fig. 3). During the stakeholder meetings, data from the baseline survey are presented to describe the current disease situation. All stakeholders have an equal chance to participate or share their opinion based on the social equity part of the EH concept. The situation and problems were analyzed and synthesized to create an effective solution. In addition, a public hearing was set for better understanding and collaboration on an action plan. The essential decisions on disease prevention and control are agreed upon, and a strong commitment is made to follow through on the plan (Sripa et al., 2017).

3.1.2 Behaviour Changing

In the Lower Mekong countries (including the northeastern region of Thailand), there is an abundance of wetlands where the occupation of the inhabitants is primarily agriculture. The way of life of the people involves wetlands and food culture, described as a '*rice—fish culture*' (Grundy-Warr et al., 2012). Because fish-borne trematodes such as *O. viverrini* are transmitted to humans via consumption of raw fish, food culture is an important risk factor for liver fluke transmission. For example, the practice of eating raw fish, a common behaviour of people in the northeast, increases the risk of infection and cancer (Grundy-War et al., 2012). Daily traditional dishes usually consist of fish from local water bodies. Cyprinoid fish (Pla-khao) such as *Cyclocheilichthys apogon, Hampala dispar and Osteochilus hasselti* are abundant in Lawa Lake. They are noneconomic fish that serve as a low-cost protein diet (Kim et al., 2017). These recipes are found widely in the northeast of Thailand and Lao PDR and include dishes such as *Koi-pla* (raw minced fish salad), *Pla-som* (raw short-fermented fish) and *Pla-ra* (long-fermented fish). Consumption of these dishes increases the risk of *O. viverrini* transmission (Prasongwatana et al., 2013). At least 74% of people around Lawa Lake consume these dishes many times a year, and 12% eat dishes with raw fish more than once a week (Sripa's unpublished data). Furthermore, social network analysis has shown that food-sharing networks can be important pathways of transmission in the community (Phimpraphai et al., 2017; Saenna et al., 2017). Identifying the important nodes of sharing and then targeting intensive health education at those nodes can be effective in prevention and control. Transdisciplinary activities involving the VHVs gradually change this risky eating behaviour.

The other behaviour that promotes the liver fluke transmission is open defecation. Although every household has an installed latrine, open defecation can occur away from households. Every morning, fishermen begin working at 2–3 a.m. at Lawa Lake. They are busy with fishing and net dropping for several hours. During that period of time, they may need to defecate, but there are no facilities nearby, so they probably defecate in the lake. Studies using GPS tracking data on the fishermen (Kim et al., 2017) and coliform bacteria detection might support this hypothesis (Kaewkes et al., 2012).

The most effective way to change these behaviours is to make the community aware of the problem and manage it themselves. VHVs and HPHs use various methods to urge each household to understand the nature of the disease (such as education about the liver fluke life cycle) and about the outcomes, including economic losses. For instance, the operation called '*Sai Seub Pa Lang or Dinner Detectives*' is run by the VHVs. They monitor households that have fish meals and warn that if raw fish consumption continues, the violators could be banned from village society.

3.1.3 Village Health Volunteers and Health-Promoting Hospitals

Health volunteers are an important key actor at the community level. The concept of using community members to provide basic health services to their community has a 50-year-old history. In Thailand, this concept is useful for disease control (WHO, 2007). The 'volunteers' are actually paid a salary of 600 Baht (around 20 USD)/month by the Thai government. The job description mostly involves health services at the village level. Once community mobilization occurs, it continues unabated. In the Lawa model, VHVs make a valuable contribution to basic health services. They are carefully selected, well-trained and accepted by the village society. The knowledge of liver fluke prevention and control is instilled in the training program, which focusses on understanding the nature of the disease that leads to effective prevention and control. The information is updated regularly. Health promotion could not be successful without the existence of the HPHs. The HPHs work as the '*point of contact*' between villagers and health officers at different levels.

3.1.4 School Involvement

For sustainable control, awareness of the younger generation should be stimulated. Changing basic attitudes should be initiated in the first years of school. Knowledge and useful information on the liver fluke and its prevention and control have been instilled in the curriculum of the fourth to the sixth graders in the schools around Lawa Lake. This information is conveyed indirectly to their parents to urge them to be aware of the disease. Currently, this idea has been adopted nationally for schools in endemic areas throughout Thailand. School activities include parades, knowledge and drawing contests, exhibitions that discourage the attitude of eating raw fish and prevention of the disease. Another school activity that encourages school children and teachers to be aware of the disease is the '*Liver Fluke—Free School*'. This is one of signatures of the Lawa model. The students in both primary and secondary schools are surveyed for liver fluke infection. Infected students are treated until cured. After 3 years of implementation, if all students are free from liver fluke infection, a prominent billboard is awarded to the school as a certificate declaring the school free of infection (Sripa et al., 2017). This activity works well among the schools around Lawa Lake.

3.1.5 Local Government

Even with all these activities, long-term control could not be achieved without government support of the policy. Local governments have an important role in supporting the community both financially and socially. In the Lawa model, the SAO has the support of the Lawa community in health control, including liver fluke control. Routine examination and campaign activities are mainly supported by SAO.

3.2 Scientific Support

The Lawa model is transdisciplinary with integrated control of the liver fluke and planning and decisions based on scientific evidence. Data and information are the outcome of research studies. With good collaboration among stakeholders, including the TDRC-KKU research team, the data are analyzed scientifically before being returned back to the community for planning and decision-making. Furthermore, the TDRC-KKU also arranges training courses in liver fluke diagnosis for health personnel who work in the community. The training includes an update on relevant knowledge and information for the community. The publication of data and information in scientific journals benefits the research community (Sripa et al., 2017).

4. ANIMAL RESERVOIRS

4.1 Role of the Reservoir Host in Human Opisthorchiasis (See Also in Tangkawattana and Tangkawattana, 2018)

Fish-eating mammals such as dogs and cats are the main reservoir hosts of opisthorchiasis. They are infected by eating raw contaminated fish. As in the human host, the infective stage metacercariae excyst in the duodenum and migrate to become mature worms in the bile duct of the host. As a reservoir, cats are more important in sustaining the liver fluke than dogs in endemic areas (35.5% prevalence vs. 0.4% in dogs) (Aunpromma et al., 2012). These reservoir animals have subclinical disease with few or no symptoms. The animal reservoir spreads the parasite eggs through their faeces. In endemic areas where there are wetlands, the eggs in faeces are transferred to water bodies or perhaps seasonal flooding facilitates the transportation of the egg to the water reservoir. Although cats and dogs are carnivorous, domestic animals do not chase prey. Dogs and cats are probably infected by consuming fish scraps and leftover food with contaminated fish. Furthermore, they sneak into open kitchens and garbage cans for fish remains, fish scrap and leftover fish. The infected animals transmit the parasite eggs via defecation into the environment. In remote endemic areas, pet care and hygiene need to be improved.

4.2 Integrated Control in the Reservoir Host (See Also in Tangkawattana and Tangkawattana, 2018)

Animal health volunteers, who are involved with the host reservoirs (cats and dogs), are invited to join the stakeholder meetings. Animal health volunteers were created a few years ago by the Department of Livestock Development, Ministry of Agriculture. Their responsibility involves animal health care and promotion in both companion and livestock animals. Most are also VHVs; therefore, they are involved with both the human and animal aspects of control. However, their main duty focusses on human health. Owners should take responsibility for control of infection in collaboration with the community. The following guideline is suggested for the owner and community. First, owners should understand the nature and importance of the disease as it relates to animals as well as improve pet care and attitudes towards animal health. Then deworming should be done regularly using PZQ every 6 months, together with vaccination. Animals should be prevented from accessing areas such as the kitchen and trash bins. Waste from the animal should be well managed to prevent the transmission of parasite eggs to the environment. Last but not least is controlling the animal population—the most difficult part. Local regulation and policy should provide support for the effective control of the animal reservoirs.

5. ECOSYSTEM AND INTERMEDIATE HOSTS

5.1 Ecology of Infection

The Lawa wetland area is the perfect ecosystem for the parasite that causes opisthorchiasis. The geography of water bodies and surroundings facilitates the development of the parasite in each host and environment. A baseline survey in 10 villages around Lawa Lake revealed interesting information (Fig. 4). On the eastern side of the Lake, where most villages are located, the prevalence of infection in each village showed a gradual increase from south to north, despite similar cultures and behaviours. For example, NNK village in the south of the lake and KSR in the north have prevalence of 74% and 15%, respectively.

The ecological significance of the *Bithynia* snail in fluke transmission dynamics is reflected in the altered landscape epidemiology (Sripa and Echaubard, 2017). Our study indicated a high abundance of the first intermediate host (*Bithynia* snail) and the second intermediate host (cyprinoid fish) near the shore of the southern part of the lake. This abundance is the result of the alteration of water flow, sediment flow and the downstream environment caused by dam construction (Kim et al., 2016). Furthermore, *Bithynia* snail habitat requires such a high level of salinity and nitrite–nitrogen compound that other freshwater snails could not tolerate. Nitrogen and nitrite from agricultural uses and household wastewater contaminate the small stream that flows to the southern region of Lawa Lake. This reflects species-specific differences in snails that correlate with salinity and nitrogen

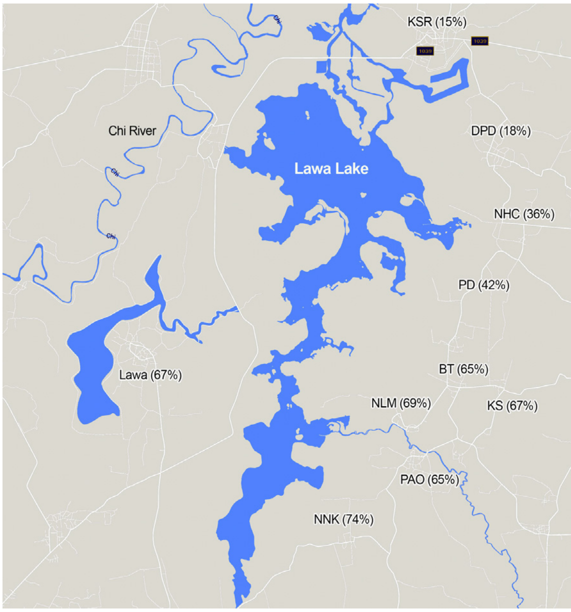

Figure 4 Gradient increase of *O. viverrini* prevalence of 10 villages around Lawa Lake leads to elucidation of the role of environment to hosts. The given abbreviations are names of the villages.

(Kim et al., 2016). Similarly, by a study (Wang et al., 2017) in three sites in endemic areas in the northeast of Thailand, the role of landscape connectivity (the extent that the landscape facilitates or hinders movement, acting as a barrier or conduit of host movements) between humans and the first intermediate host of *O. viverrini* transmission was explored. The study revealed the relationship of faecal contamination sources on the risk for snail infection in humans (Wang et al., 2017).

Kim et al. (2016) also noted the nitrogen–salinity gradient and higher relative abundance of cyprinoid fish in the vegetated regions of the southern part of the lake. Furthermore, this study detected the highest levels of coliform bacteria in the water at the southern shore where the fishermen's boats were docked. Presumably, this is caused by open defecation because the location is far from households where latrines were installed. Additionally, faecal coliform was detected from the small stream with contaminated waste from the villages around Lawa Lake. Leakage of waste from households and livestock production was probably involved. The abundance of intermediate hosts and contaminated faecal coliform is highest during the rainy season (August–October), implying that *O. viverrini* transmission has a strong seasonal transmission involving the *Bithynia* snail (Sripa and Echaubard, 2017). An additional factor is flooding. The Lawa wetland complex is a seasonally flooded wetland. Flooding usually occurs annually from October to November. This seasonal flooding would facilitate the transmission of the liver fluke eggs into ecosystem. The human—animal—environment interface is most prominent in the southern part of the lake, where the prevalence of cats, the main animal reservoir around Lawa Lake, is highest (see also in Tangkawattana and Tangkawattana, 2018).

5.2 Intermediate Hosts Versus Environment

Lawa Lake has an abundance of the intermediate hosts of *O. viverrini*, with the appropriate wetland habitat that enhances reproduction of the specific species for *O. viverrini* infection. The *Bithynia* snail (*Bithynia siamensis goniomphalos*), the first intermediate host of *O. viverrini*, is found widely in the northeast of Thailand. The snail habitat includes fresh water reservoirs, clear shallow ponds, marshes and irrigation canals (Petney et al., 2012). The *Bithynia* snail exists in water depths from 30 cm to 10 m (Ngern-klun et al., 2006; Petney et al., 2012; Tesana, 2002). However, most *Bithynia* snails in the Lawa wetland are found in shallow water less than 50 cm. The snail's preference includes not only shallow water but also water of high salinity. The snail lives in water with a salinity ranging from 0.05 to 22.11 ppt and with surface salt less than 1% (Suwannatrai et al., 2011). The snails live in water having a temperature between 18 and 33°C, pH from 6.3 to 8.5, dissolved oxygen 2—10 mg/L and turbidity ranging from 8 to 450 FTU (Lohachit, 2001). Our team also reported an abundance of *Bithynia* snails in high-salinity water (average 3.65 ppm) (Kim et al., 2016). Furthermore, the water with high nitrite—nitrogen is preferable habitat. Understanding the nature of the intermediate host is one of keys for successful control.

The second intermediate host of *O. viverrini*, the cyprinoid fish, is infected by cercariae shed from the snail in the next step of development. Cyprinoid fish that are susceptible to *O. viverrini* infection include the genera *Cyclocheilichthys* sp., *Puntius* sp. and *Hampala* sp. (Vichasri et al., 1982). According to the study in Lawa Lake by Kim et al. (2016), fish in Lawa Lake have their own territory. The susceptible species reside mostly in the southern region of the lake where they are the only species that are able to adapt to the higher salinity water. The fish do not travel far from suitable territory. With this knowledge about hosts and the ecosystem, a tailor-made control program can be designed for solving the problem of opisthorchiasis in humans.

5.3 Ecosystem Approach to Health

The Lawa model is a good example of an integrative control program using the ecosystem approach for disease control. With the systems thinking of the Lawa model together with EH/OH approach, we focus on interruption of the parasite life cycle (Fig. 1). The information from our studies indicates how the environment, intermediate hosts and reservoir hosts relate to disease transmission. The southern part of the lake has a high prevalence of all hosts, which reflects how the human–animal–environment relates to health and disease. Therefore, effective control should be based on prevention and control in each host and adjustments in the environment to interrupt liver fluke transmission. Control strategies might take advantage of knowledge, for example, a temperature above 40°C could destroy the parasite eggs in faecal waste, and the intermediate host has seasonal pattern of *O. viverrini* transmission (Echaubard et al., 2017). Thus, human waste treatment using evaporation, solar drying plant or eco-friendly drying in the sun over 3 weeks to kill the parasite eggs may prevent snail infection in endemic areas. Also, retrenchment of the shoreline to deeper than 1 m might cause a decline in the population of the *Bithynia* snail (Sripa et al., 2015, 2017). This knowledge could serve as the background for designing a control program targeted on breaking the transmission. Community participation together with work among disciplines will lead to the effective and sustainable control of the liver fluke. Surveillance of transmission through the intermediate hosts could be a tool for long-term monitoring.

6. FROM APPROACH TO CONTROL

6.1 From Holistic Approach to Practice

Tackling the liver fluke problem using a holistic approach to disrupt the parasite life cycle is the core of Lawa model. Knowledge of the human, animal and environment along with the six principles of EH (systems thinking, transdisciplinary research, participation, sustainability, gender, social equity and knowledge to action) is implemented in the Lawa model. In the initial phase, the TDRC-KKU research team examined the status of infection of all hosts in a baseline survey. They then identified stakeholders and engaged with them to encourage participation. The community learns of the status of liver fluke disease in the area and works with one another to solve the problem. In focus groups and discussion, the people learn more of the specifics of the problem. Empowerment of health volunteers and hospital staff is necessary to sustain an effective for long-term practice. Finally, the new generation is prepared to protect the community from the disease and maintain awareness in the future (Sripa et al., 2017).

6.2 Surveillance and Disease Control

Although the prevalence of *O. viverrini* has declined, surveillance of the disease cannot be ignored. Multidisciplinary, multisectoral officers and workers must participate in activities to sustain the disease control. One activity is regular stool examination of people in the community to monitor infection status. Faecal examination is integrated into the routine work of HPHs in community. Well-trained local health officers have the ability to perform faecal examinations and train other health officers from other HPHs. The knowledge and skills of local health officers are regularly evaluated by Khon Kaen University for quality control.

In addition, surveillance of intermediate hosts, reservoir hosts and the Lawa wetland environment is conducted in conjunction with the TDRC-KKU. Monitoring the disease can be done through the transmission to intermediate hosts such as snails and fish or reservoir hosts such as cats and dogs, but examination of the intermediate host is more convenient in practice. The community will take on these tasks in the near future.

According to WHO principle for helminthiasis control and elimination plan, there are several steps for achievement; it focuses on mortality, prevalence, transmission, surveillance and elimination (Bergquist et al., 2009). Based on this WHO principle, the aim of the Lawa model is to reduce the prevalence of opisthorchiasis to less than 1% in humans and to zero in intermediate hosts and reservoir hosts within the next 10 years. The knowledge from our investigation on the nature of liver fluke infection and its intermediate hosts is promising that we can meet the ultimate goal, elimination of the disease in the near future. Fig. 5 shows the steps of liver fluke control in the Lawa model starting from the period having high human morbidity in 2007. We are now at the transmission step. Infection in humans, reservoir hosts and intermediate hosts has declined since the implementation of the Lawa model. Since the Lawa community has committed to push the control step forward to elimination in the next 10 years, the community is expected to be the fluke free in the near future.

6.3 Sustainability Buildup

To achieve the elimination milestones, the suitability and sustainability of the disease control activities must be ensured. Sripa et al. (2017) emphasize

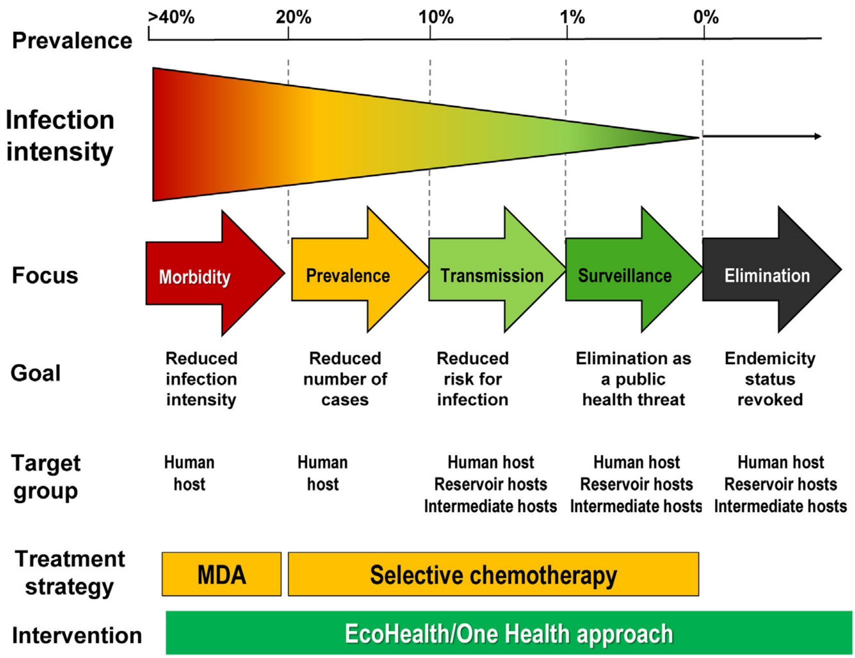

Figure 5 Control and elimination plan/milestones for opisthorchiasis control. *Modified from Bergquist, R., Johansen, M.V., Utzinger, J., 2009. Diagnostic dilemmas in helminthology: what tools to use and when? Trends Parasitol. 25, 151–156.*

the need for community participation using local HPHs as the point of contact or point of entry and VHVs as a key player, the infantry in the battle against the disease. All stakeholders have a chance to freely participate in all of the meetings and reach consensus on control activities. All key players have been empowered for the long-term. The activities are incorporated into their routine work with the support of the local administration office or subdistrict administrative office. School activities are necessary for sustainable control. Integrating knowledge into the school curriculum and changing attitudes towards eating raw fish to prevent liver fluke infection will help ensure that the next generation will be free from the disease. These all activities are based on EH/OH assessment and encourage the stakeholders to take ownership of the Lawa model. One example that reflects sustainability is community participation, which had increased from a functional level in the beginning to an interactive level at present.

Operation of the control program applies principles of monitoring and evaluation, but all activities are flexible and can be adjusted as appropriate.

Recently the National Research Council evaluated the cost-effectiveness of the Lawa model. The results showed that 1 Thai Baht of investment in the Lawa model would give a social return on investment of 3.47 Thai Baht (347%) (Kaosa-ard, 2017). This reflects how the value of the project pays back society.

The Lawa model engaged policy makers from the community to the national level. Implementation needs their permission, support and coordination to proceed. Several groups from Khon Kaen University convinced health officials of high rank of Thailand and local politicians to place the liver fluke and cholangiocarcinoma on the national agenda at the eighth National Health Assembly by the end of 2015. With the cooperation of the Liver Fluke and Cholangiocarcinoma Research Center, Cholangiocarcinoma Screening and Care Program (CASCAP), KKU and MoPH, the projects to eliminate opisthorchiasis and cholangiocarcinoma were established. The project has been implemented in 84 endemic districts since 2016 (Sripa et al., 2017). The agenda focusses liver fluke and cholangiocarcinoma control at the primary, secondary and tertiary health care levels. The Lawa model was chosen to be a control model for primary health care at the community level. The agenda aims to eliminate the liver fluke infection within 10 years (Sripa et al., 2017).

Since the success of the Lawa model is well known throughout Thailand, our neighbouring countries (such as Lao PDR, Cambodia, Philippines and others) have adopted the concept of the Lawa model not only for opisthorchiasis but also for other diseases such as trichinellosis, soil-transmitted disease (STHs), schistosomiasis and vector-borne diseases. The Lawa model has been recognized as one of the two showcases with successful parasitic control programs of the WHO Neglected Zoonotic Disease (Sripa et al., 2017; WHO, 2015). Nowadays, the Lawa model/EcoHealth/One Health concept is recommended in integrated control of food-borne diseases in the Expert Consultation to Accelerate Control of Foodborne Trematode Infections, Taeniasis and Cysticercosis by WHO/WPRO (WHO, 2017).

7. CONCLUSIONS AND FUTURE PERSPECTIVES

7.1 Holistic Approach and Systems Thinking

The concept of disease control based on systems thinking and a holistic approach incorporates the common sense idea of targeting the interruption of liver fluke transmission is the core of the control program of the Lawa model. Active participation of the community with effective VHVs and with HPHs as the point of contact facilitates control activities to achieve the desired goals. The information from surveys and research has supported the decision and backup plan for the best operation.

7.2 From Problem to Wellbeing

In the past, northeastern areas of Thailand were the super-endemic area for liver fluke infection caused by *O. viverrini*. A lack of understanding of the nature of disease, the existence of a perfect environment for the parasite hosts and the culture and lifestyle of people in this area were the major problems of public health control. With this new approach of the Lawa model, the prevalence of infection has dramatically declined. Nonetheless, the ultimate goal of the Lawa model is not only to stop disease transmission but also to promote the wellbeing of the people in community. The Lawa model aims to eliminate the liver fluke infection in Lawa community within 10 years.

7.3 The Disease Model

Our success has attracted researchers to discover more about liver fluke infection and incorporate empirical evidence into the Lawa model (Sripa et al., 2017). The control model is dynamic and expected to be sustained in the community. New tools and techniques have been instilled into the Lawa model time to time such as quantitative modelling for analysis transmission dynamics (Sripa et al., 2015). For example, a mathematical model indicates that human and intermediate hosts are not only reservoir hosts but also are necessary to maintain transmission of the liver fluke in Lao PDR (Bürli et al., 2018). In addition, cats and dogs cannot sustain the transmission in the absence of humans. The authors suggested that intervention in humans only is enough to stop the transmission. However, this assumption requires further evidence in different scenario such as in the lake region rather than the rice paddies. A mathematical model of liver fluke transmission dynamics in the Lawa area is under investigation by our team.

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