CHAPTER 1

INTRODUCTION

Statement of the problem

Studies on Thai caddisflies have been confined mainly to descriptions of the adult stages, and relatively few larvae have been characterized adequately (Malicky and Chantaramongkol, 1991; Malicky, 1999; Thamsenanupap *et al*., 2005). Unfortunately, identifications of larvae are required more frequently than are identifications of adults, especially in biological surveys and biomonitoring. There is still a tremendous gap between capacity to identify adult stages and ability to recognize larvae or associate them with known adults. In part, this is because of the holometabolous life cycle of caddisflies, with a pupal stage which complicates larval rearing and ensures that none of the features of the adult are reflected in the final-larval instar. As a result, reliable identification of species on the basis larvae alone is not possible, and adult material is indispensable for the determination of species. This obstacle also affects workers dealing with the relatively well-studied fauna of Europe and North America, although the situation is much worse in tropical Asia (Malicky, 1983).

The Hydropsychidae is a large and dominant family of caddisflies living in running water on all landmasses of the globe except South America and Antarctica (Wiggins, 1996). In regions like Europe and North America, where their taxonomy and biology are well known in both the adult and larval stages, hydropsychids are used as the most accurate and cost effective indicators of water quality because the immature stages are the ones that are exposed to pollution (Resh, 1992; Morse, 2003). In the rest of the world, including Thailand, where threats to the aquatic environment are severe, most species remain undiscovered and undescribed, and taxonomic expertise, literature, and identification tools are severely limited (Dudgeon, 2000).

The taxonomy of Trichoptera is based almost exclusively on adult male genitalia, with most females, larvae, pupae, and eggs remaining unidentifiable (Morse, 2003). It is not possible though, to determine the species of an immature without knowing the adult. In this case, adult taxonomy has to be established first, followed by larval/adult associations. Therefore, a study describing the larvae of Thai hydropsychid species and associating them with known adult form is sorely needed. The goal of this study is to develop techniques allowing ecologists and resource managers to identify hydropsychid larvae to species-level.

To attain this goal, this study associated unknown larvae with described adults, and then described the larvae. Associations were accomplished using three techniques:

1) Rearing mature larvae to adults in the field and laboratory.

2) Examining the details of structures on the head, thorax, and abdomen of larvae using two techniques; a dissecting microscope with camera lucida and scanning electron microscope.

3) Assaying some larvae and adult hydropsychid species at the molecular level.

Introduction to the order Trichoptera

The scientific name of the caddisflies (*Trichos* = hair, *ptera* = wing) refers to the covering of unmodified setae over the wing surfaces of most species. Adult caddisflies are moth-like insects with wings that are covered by fine hairs. The antennae are long and filiform, and the wings are folded tent-like over the abdomen. Typically, adult caddisflies are dull colored, but a few tropical taxa (such as the Macronematinae) may be boldly marked in yellow or white and black. The adults ingest liquid only, such as nectar (e.g. Nozaki & Shimada, 1997), although some of the mouthparts, the labial and maxillary palps, are well developed. They live for around a month (although this varies among species). Most are nocturnal or crepuscular, but some brightly colored Macronematinae (among others) are diurnal. Mating follows swarming or courtship behavior (which can involve sex pheromones), and may take place among riparian vegetation or on the ground. Eggs are laid in or immediately above the water. Larvae can be found in almost any type of freshwater habitat, and are a major component of the stream benthos. There are generally five larval instars. Many species are univoltine although bivoltine and trivoltine life histories can occur. Pupation invariably occurs under water, and the pupae are enclosed inside a cocoon within a pupal case that was built by the larva and affixed to the substrate. The pupae have large mandibles which are used to free the emerging pharate adult which is cloaked within the pupal integument. It nevertheless swims to the surface and moults to the winged adult stage. The pupal case is usually a modification of a moveable larval case or fixed shelter, and the ability of caddisfly larvae to build such structures out of organic or inorganic materials has been a source of fascination for many observers (reviewed by Dudgeon, 1999).

Diversity and classification of the order Trichoptera

The caddisflies (Trichoptera) are an order of holometabolous insects found on every continent except Antarctica. Larvae are aquatic and occupy virtually all types of freshwater ecosystems. There are currently approximate 11,000 species of caddisflies known from all regions of the world (Morse, 2001) with many new species being described every year, primarily from the Neotropical and Oriental regions (e.g., Flint, 1991; Malicky and Chantaramongkol, 1999). The success and diversity of the Trichoptera in freshwater is attributed to their use of silk to assist in mobility, food acquisition, and retreat construction (Mackay and Wiggins, 1979). The world species are in 504 genera in 45 families. Most species have been described in the microcaddisfly family Hydroptilidae, with nearly 1,700 species. Other well-represented families globally include the long-horned caddisflies (Leptoceridae, over 1,500 species), the common net-spinner caddisflies (Hydropsychidae, over 1,400 species), and the northern caddisflies (Limnephilidae, almost 900 species). The highest known species diversity and the greatest density of species occurs in the Oriental Biogeographical Region (over 3,700 species, with 1.6 species per kilohectare) (Morse, 2003).

The world family Hydropsychidae is composed of five subfamilies: Arctopsychinae, Diplectroninae, Macronematinae, Smicrideinae and Hydropsychinae (Schefter, 1996). Some workers, such as Lepneva (1970), Schmid (1968), and Malicky and Chantaramongkol (1993) considered that the subfamily Arctopsychinae should be raised to family status and becomes the Arctopsychidae. In Thailand, Malicky and Chantaramongkol (1993) divided the family Hydropsychidae Curtis, 1835 into 3 subfamilies as follows:-

Subfamily Diplectroninae Ulmer 1951

Genus *Diplectrona* Westwood 1839

Subfamily Hydropsychinae Curtis 1835

Genus *Cheumatopsyche* Wallengren 1891

Genus *Hydatomanicus* Ulmer 1951

Genus *Hydromanicus* Brauer 1865

Genus *Hydropsyche* Pictet 1834

Genus *Potamyia* Banks 1900

Subfamily Macronematinae Ulmer 1907

Genus *Aethaloptera* Brauer 1875

Genus *Amphipsyche* MacLachlan 1872

Genus *Macrostemum* Kolenati 1859

Genus *Oestropsyche* Ulmer 1957

Genus *Polymorphanisus* Walker 1852

Genus *Pseudoleptonema* Mosely 1933

Genus *Trichomacronema* Schmid 1964

Characteristics of family Hydropsychidae

The Hydropsychidae is a large and dominant family of caddisflies living in running waters (lotic); a few species occur along wave-washed shorelines of lakes. Hydropsychid caddisflies are extremely important in the ecology of running water systems because of their ubiquitous occurrence, abundance, and large biomass. Approximately 128 species are recorded in Thailand (Malicky and Chantaramongkol, 1999, 2000; Malicky, 2002).

Hydropsychid larvae (Figs. 1.1-1.6) are distinguished from all others by the sclerotization of the dorsum of each thoracic segment, combined with branched gills on the ventral surface of the abdomen and last two thoracic segments, usually with a tuft of long setae near the apex of each anal proleg. The sclerotized plates of the mesonotum and metanotum do not have a median dorsal ecdysial line, although the line does occur on the pronotal plates; in some subfamilies, the last two thoracic notal sclerites have a transverse ecdysial suture. In some genera and perhaps all, first instars lack gills, and might then be confused with the final instar of the Hydroptilidae; but the first instar of Hydropsychidae can usually be distinguished by the lobate hind margin of the metanotal plate. Characters of the gills and other structures diagnostic for hydropychid genera are not fully developed in early instars. Larvae have dense brushes of setae at each side of the labrum that probably function in feeding. On the venter of segment VIII in most genera and IX in all genera possess a pair of sclerites with stout, backward-directed setae that probably serve in locomotion. Secondary setae are richly developed in the Hydropsychidae, and serve a useful role as taxonomic characters. A lexicon of setal types has been applied to the problem of larval taxonomy for species of *Hydropsyche* (Schefter and Wiggins, 1986). Chaetotaxy provides characters that are more consistent than the color patterns of sclerotized parts, and is also capable of finer resolution among species and higher taxa.

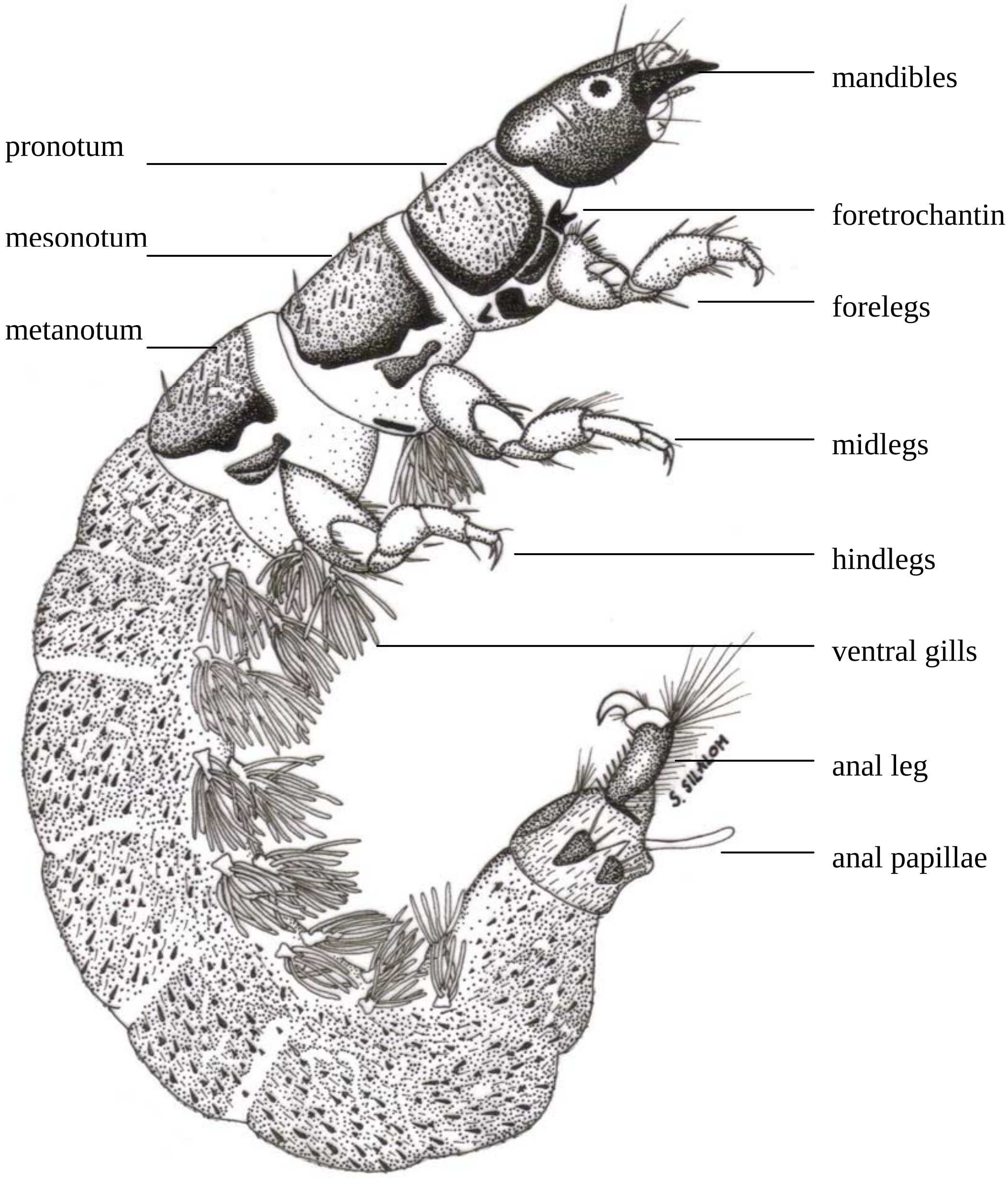

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Figure 1.1 General characters of Hydropsychidae: *Hydatomanicus adonis* larva, lateral aspect.

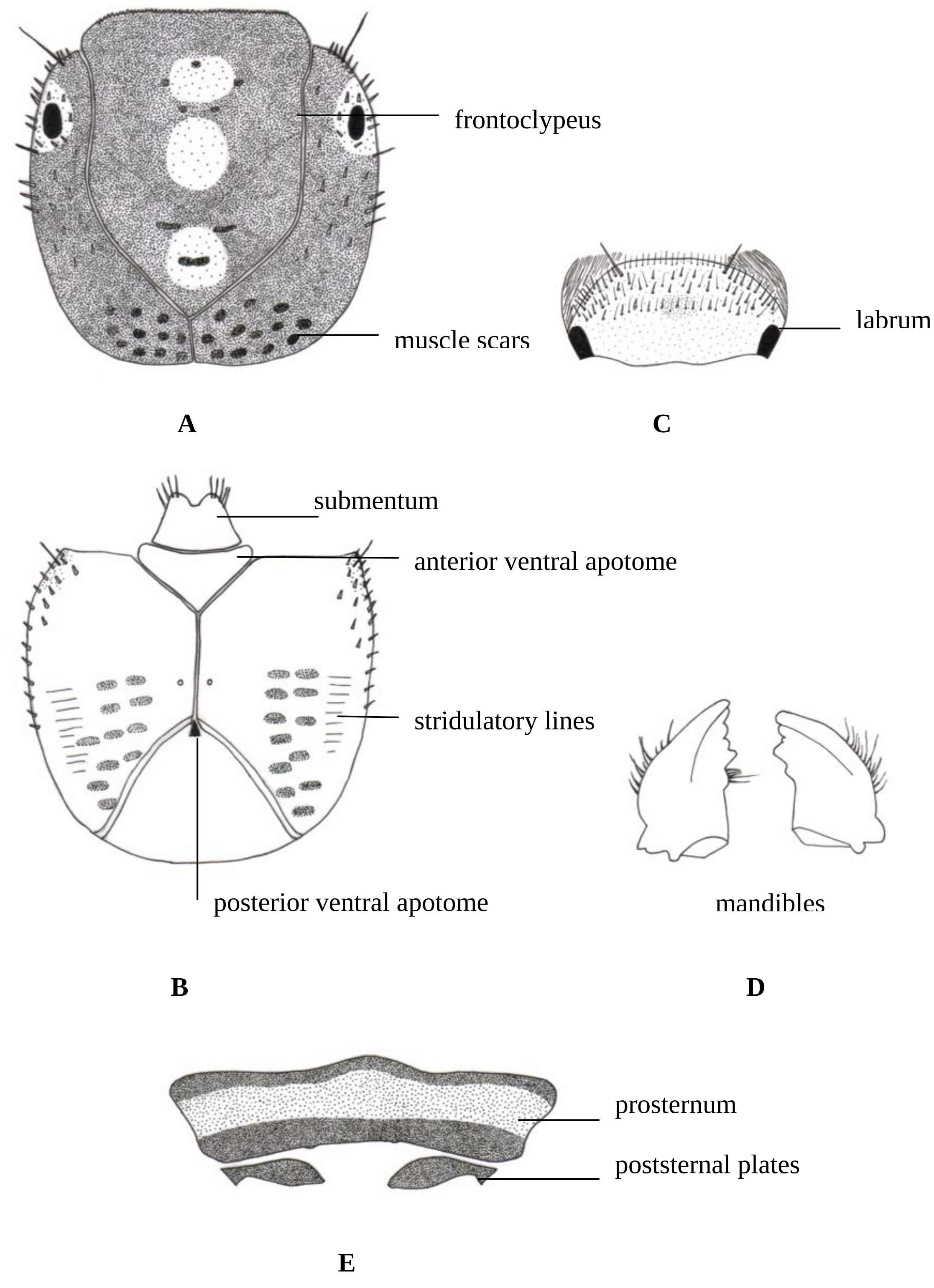

Figure 1.1 (continued). *Hydatomanicus adonis* larva: A, dorsal aspect of head; B, ventral aspect of head; C, dorsal aspect of labrum; D, ventral aspect of mandibles; E, prosternum.

Hydropsychid larvae are best known for the elegant silken capture nets they spin to strain food from the current. Studies in Europe and North America have revealed intricate details of the net-spinning behavior by which larvae in different genera weave meshes of certain dimensions, specializing their filtering for food particles of a particular size range. Larvae in the Macronematinae occur in slow currents of downstream sites, and spin nets with the smallest mesh size to filter small particles suspended in the current. Larvae of Hydropsychinae occupy sites between these two extremes, and spin meshes of intermediate size range. Food studies on larvae in several genera indicate that algae, fine organic particles, and small aquatic invertebrates are ingested (Wiggins, 1996).

Larvae of *Hydropsyche* are able to produce sound by stridulating. A ridged area on each side of the ventral surface of the head is rubbed over a raised tubercle on the dorsal edge of each femur. When stridulating, the forelegs are anchored firmly on the retreat or net, and the head is thrust rapidly forward and backward, engaging the file and scraper mechanism on both sides simultaneously (Wiggins, 1996).

All three subfamilies of the Hydropsychidae are represented in Thailand; following are the genera in each subfamily and a summary of larval characters.

Diplectroninae: *Diplectrona* Head tending to be globose; frontoclypeal sutures sigmoid or nearly so; mandibles with teeth distributed along mesal edges; ventral apotome of head divided into two parts, both parts approximately the same length; ventral ridges of head usually broken by longitudinal gaps, the roughened area broadly tapered posteriorly in outline; meso- and metanotal plates subdivided by transverse ecdysial line; abdominal and thoracic gills sparsely branched, some branches arising along central stalk, most of the gills arising from apex of stalk; lateral gills, when present, reduced to short lobes; sclerites on venter VIII ovoid (Wiggins, 1996).

Hydropsychinae: *Cheumatopsyche*, *Hydropsyche*, *Potamyia*, *Hydatomanicus*, and *Hydromanicus* Head tending to be quadrate as seen in dorsal view, the dorsum flattened; frontoclypeal sutures generally more nearly straight than sigmoid; mandibles with teeth distributed along mesal edges; ventral apotome divided into two parts, the anterior ventral apotome quite large, the posterior part minute; ventral ridges of head not broken, the entire roughened area generally rectangular; fore trochantin frequently forked; meso- and metanotal plates not subdivided transversely; abdominal and thoracic gills with lateral branches numerous; lateral gills when present reduced to short lobes; sclerites on venter VIII triangular and elongate (Wiggins, 1996).

Macronematinae: *Macrostemum*, *Pseudoleptonema*, and *Trichomacronema* Mandibles with teeth distributed along mesal edges; anterior ventral apotome not fully delimited, ecdysial line absent on right side, posterior part minute; meso- and metanotal plates not subdivided transversely; abdominal and thoracic gills feather-like, apical and lateral branches equally dense, lateral gills similar to ventral gills; sclerites lacking on venter VIII. Foretrochantin never forked (Wiggins, 1996).

Importance of Trichoptera

Caddisflies are one of the major groups of macroinvertebrates in freshwater ecosystems both in terms of species diversity and of density, especially in relatively unpolluted waterways. For this reason, they are significant contributors in the processing of nutrients. The collecting-gathering and collecting-filtering and scraping caddisflies help concentrate the nutrients of fine particulate organic matter into their own bodies, making the nutrients available to invertebrate and vertebrate predators in the food web. On the other hand, shredding- herbivores and shredding-detritivores and predators help break coarse organic materials into small particles, including feces, that can then be used by many animals that are able to ingest only fine bits of organic material. Because of the many different feeding strategies and habitat preferences of this diverse order, nearly every conceivable food resource is processed by caddisflies.

Although caddisflies generally will not tolerate even moderate levels of pollution, the range of tolerance is wide among the various species of caddisflies. For this reason and because of the usually high species diversity and density of caddisflies in unpolluted surface waters, communities of Trichoptera and other macroinvertebrates are often used to detect the presence of pollution. The occurrence of several of the less-tolerant species and high densities of large numbers of species of caddisflies suggest that the water is relatively unpolluted. Pollution may be detected with this technique more reliably and more cheaply than with chemical analyses. Once it has been established that a given waterway is polluted, follow-up analyses may then be attempted to discover the specific polluting substances or microorganisms and their concentrations. Finally, equipped with those data, land managers, engineers, economists, politicians, and other responsible decision makers may be better able to determine appropriate mitigating measures to reduce or eliminate the pollution (reviewed by Morse 2003).

In forensic entomology, the casing of caddisflies can also be used to determine how long a body had been in water (e.g. to answer the question when it was dumped in the water). In a case from the 1950s, a caddisfly casing (most likely of *Limnophilus flavicornis*) contained the fibers of the red socks that were worn by the deceased. However, the fibers were only found at the very top and the very bottom of the casing, which meant that the caddisflies had, for the most part, already built their casing and then finished it at the corpse (fiber on top), and after that and attached it to the red sock (fiber on bottom). Because the attachment procedure takes at least a few days, it was estimated that the body has been in the water for at least 1 week (Benecke, 2004).

Previous caddisfly taxonomic research in Thailand

Caddisflies in Thailand have been researched since 1931 by Martynov (Dudgeon, 1999), who reported on a collection of Trichoptera from Siam and China, and described a new species, *Stenopsyche siamensis*. In 1987, Malicky started to collect caddisflies near streams on Doi-Suthep mountain which was his first paper on caddisflies in Thailand. Later, his research cooperated with Dr. Porntip Chantaramongkol and produced a series of 36 papers, which provided descriptions and illustrations of adult caddisflies. The most recent synopsis of Thai caddisflies reported 491 species and the minimum estimation of 700 species (Malicky and Chantaramongkol, 1999). Since this report, 17 more papers (Laudee and Malicky, 1999; Malicky, 2002; 2005a; 2005b; 2006; Malicky and Chantaramongkol, 2000; 2003; 2006; Malicky and Prommi, 2006; Malicky *et al.*, 2000a, 2000b; 2001; 2002; 2004; 2005; 2006; Thapanya *et al*., 2004) have reported more than 200 additional species. Consequently, over 700 species of adult caddisflies have been reported. Unfortunately, our taxonomic understanding of the immature stages of caddisflies in Thailand remains very poor.

Descriptions of several Thai caddisfly larvae were given in papers of Malicky and Chantaramongkol (1991) (*Trichomacronema paniae* Malicky and Chantaramongkol, 1991), Malicky (1999) (*Ugandatrichia maliwan* Malicky and Chantaramongkol, 1991), Laudee (2004) (*Ugandatrichia kerdmuang* Malicky and Chantaramongkol, 1991), and Thamsenanupap *et al*. (2005). The diversity of Trichoptera larvae were first studied on Doi Suthep-Pui by Silalom (2001). This work attempted to identify caddisfly specimens to the lowest possible taxonomic level, namely to morphospecies-group in *Chimarra,* but family level in most taxa.

Descriptions of additional hydropsychid larvae were recently published, including in Prommi *et al*. (2006a) (*Hydatomanicus adonis* Malicky and Chantaramongkol, 1996 and *Hydatomanicus klanklini* Malicky and Chantaramongkol, 1993), Prommi *et al.* (2006b) (*Pseudoleptonema quinquefasciatum* Martynov, 1935 and *Pseudoleptonema supalak* Malicky and Chantaramongkol, 1998) and Prommi *et al*. (2006c) (*Potamyia phaidra* Malicky and Chantamongkol, 1997).

Thesis arrangement

This thesis comprises six chapters. Chapter 1, Introduction, serves as a statement of the problem on hydropsychid larvae, introduction to the order Trichoptera, diversity and classification of the order Trichoptera, classification of family Hydropsychidae, importance of Trichoptera, and previous caddisfly taxonomic research in Thailand. Chapter 2 concerns the diversity of both adult and larva of hydropsychid species associated with mountain streams in southern Thailand, the number of hydropsychid species, as well as the number of other adult caddisflies species obtained.

The sequence of taxonomic topics covered is as follows:

Chapter 3 associates unknown larvae with identifiable adults of Hydropsychidae in southern Thailand by mean of laboratory rearing and collecting larvae and metamorphotypes.

Chapter 4 confirms the association between unknown larvae with identifiable adults of Hydropsychidae from the Chapter 3 by using molecular analysis

Chapter 5 prepares a preliminary key to the mature larvae of hydropsychid species in southern Thailand. It was considered worthwhile to attempt the construction of a preliminary key to the mature larvae of hydropsychid species in order to provide a stimulus for further work.

Chapter 6 includes the conclusion and remaining problems of this study.

Thesis objectives

This study had four main objectives:

1. To study the diversity of both the adult and larva of hydropsychid species that are associated with mountain streams in southern Thailand.

2. To associate unknown larvae with identifiable adults of Hydropsychidae in southern Thailand by means of field rearing, laboratory rearing, and molecular analysis

3. To describe larvae of hydropsychid species found in southern Thailand.

4. To construct a dichotomous key to the larval stage of hydropsychid species in southern Thailand.

Usefulness of the research (Theoretical and /or Applied)

1. An increase in knowledge of the species diversity of both hydropsychid larvae and adults in mountain streams of southern Thailand. This knowledge will provide a better understanding of their taxonomy and distribution.

2. Knowledge of species diversity of both hydropsychid larvae and adults in each region of Thailand can be used to establish regions of endemism.

3. Knowledge of larvae of hydropsychid species will enable their use as the most accurate and cost effective indicators of water quality, thereby influencing policy decisions concerning Thailand’s surface water management in the future.

Description of study areas

Thailand is situated in Southeast Asia and covers an area of nearly 513,115 km^2. The country lies between $5^0$37' and $20^0$27' north latitude and $97^0$21' and $105^0$37' east longitude (Mewongukurd, 1987). Most of Thailand’s mountain ranges can be divided into two groups. The western mountain ranges extend north-south and parallel the Thai-Myanmar border. These ranges consist of the Thanon Thong Chai, Tenasserim, Phuket, Nakhon Si Thammarat and Sankalakiri ranges. These ranges separate the narrow coastal plains along the Gulf of Thailand and the Andaman Sea. The other group of ranges begins in the north and extends southward to eastward in the central and northeastern regions of the country. This group includes the Phetchabun, Phu Pan, Sankambang, Phanom Dongrak, and Chanthaburi ranges. The country is 1,600 km long in its north-south axis and 850 km wide in the northern part. Because of its length, it is divided into two zoogeographic subregions: Indochinese subregion (northern, northeastern and central Thailand) and Sundaic subregion (peninsular Thailand). The peninsula is part of the Malay Peninsula and starts from the Isthmus of Kra at 10 degrees longitude southward in Ranong and Chumphon provinces down to the tip of Malaysia and Singapore (Corbet and Hill, 1992).

Southern Thailand consists of 14 provinces: Chumphon, Ranong, Surat Thani, Phangnga, Phuket, Krabi, Nakhon Si Thammarat, Trang, Phatthalung, Songkhla, Satun, Pattani, Yala and Narathiwat. The region, entirely located on the peninsula, extends from Chumphon to the Thai-Malaysian border and is bordered in the east by the Gulf of Thailand, to the west by the Indian Ocean.

Study sites

The twenty-four sampling sites (Fig. 1.7) covered, with permission, in this study were representative of southern Thailand, including in national park (NP), wildlife sanctuaries (WS), and wildlife management stations (WMS). This area was mountainous with waterfalls and streams. A sampling site was selected on the basis of the amount of riffle habitat in the area. Details of each sampling site is given in Table 1.1.

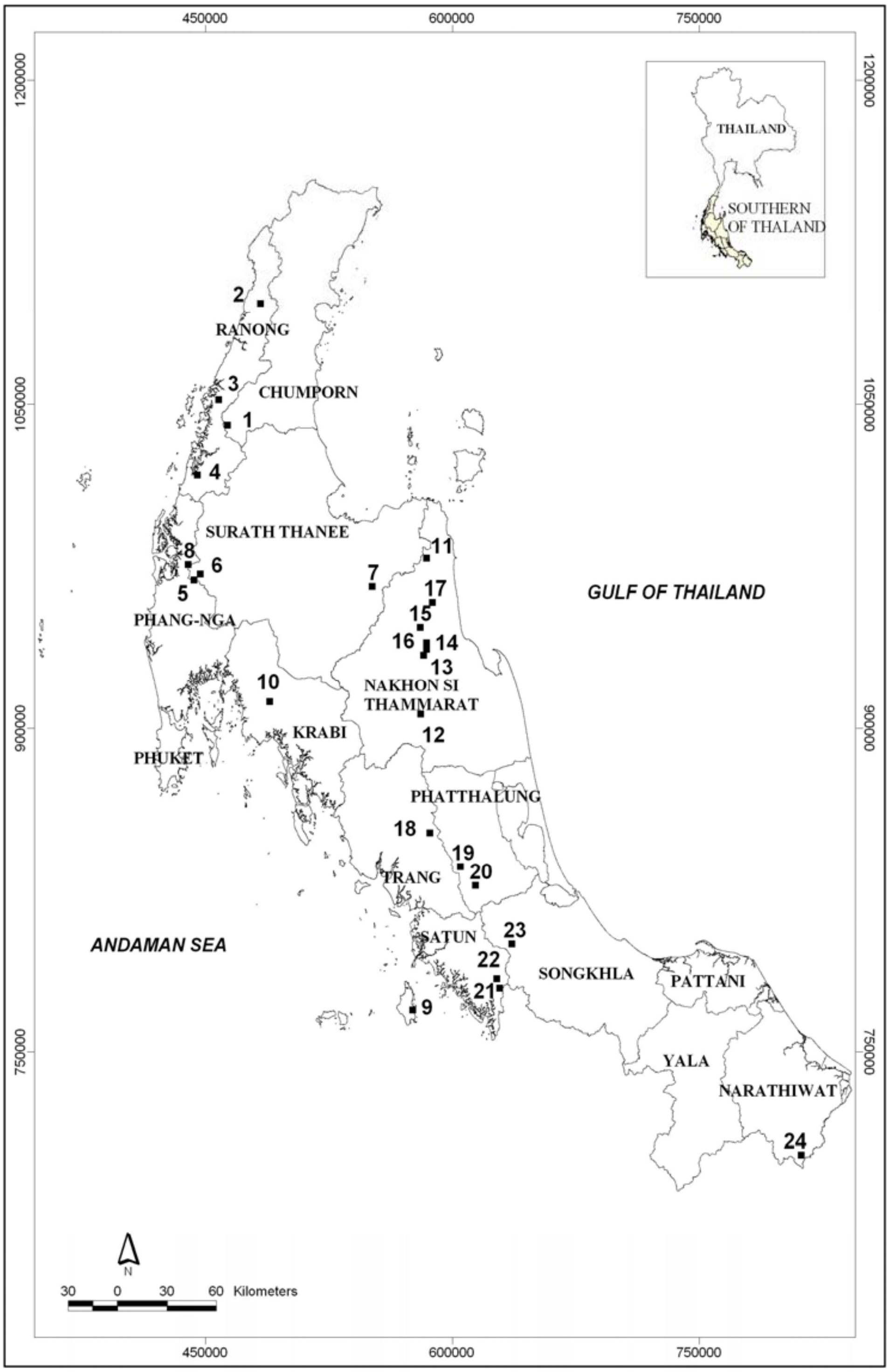

Figure 1.2 Map of southern Thailand showing locations of the twenty-four sampling sites.

Table 1.1 Details of each sampling site.

Site Code	Site name	Province	Coordination/ Elevation	Description of substrate
S1	Haew Lome Waterfall	Chumphon	09°43' N, 98°40' E/ 122 m a.s.l.	Bedrock and boulders predominant at above with a big pool, cobble, gravel and sand at below
S2	Bok Krai Waterfall	Ranong	10°22' N, 98°51' E	Bedrock and boulders predominant at above, cobble, gravel and sand at below
S3	Ngao Waterfall	Ranong	09°51' N, 98°37' E/ 50 m a.s.l.	Bedrock and boulders predominant at above, cobble, gravel and sand at below
S4	Klong Bang Mun Stream	Ranong	09°27' N, 98°30' E/ 50 m a.s.l.	Boulders predominant, cobble, gravel and sand
S5	Mae Yai Waterfall	Surat Thani	08°53' N, 98°29' E/ 287 m a.s.l.	Bedrock and boulders predominant with some sand at below
S6	Sib Ed Chan Waterfall	Surat Thani	08°55' N, 98°31'E/ 133 m a.s.l.	Large boulders predominant, cobble, gravel and sand
S7	Dad Fah Waterfall	Surat Thani	08°51' N, 99°28' E/ 236 m a.s.l.	Bedrock and boulders predominant at above with a big pool, cobble, gravel and sand at below
S8	Ton Thon Toey Waterfall	Phang Nga	08°58' N, 98°27' E/ 68 m a.s.l.	Large boulders predominant, small pool in the middle, cobble, gravel and sand
S9	Ludoo Waterfall	Satun	-	Large boulders predominant, cobble, gravel and sand

Table 1.1 Continued.

S10	Huai To Waterfall	Krabi	08°14' N, 98°54' E/ 26 m a.s.l.	Bedrock and boulders predominant at above with a big pool, cobble, gravel and sand at below
S11	Si Khit Waterfall	Nakorn Si Thammarat	09°00' N, 99°46' E/ 192 m a.s.l.	Bedrock predominant at above, deep pool in the middle, with cobble and gravel at below
S12	Yong Waterfall	Nakorn Si Thammarat	08°10'N, 99°44' E/ 112 m a.s.l.	Boulders predominant, small deep pool in the middle, cobble, gravel and sand at below
S13	Pliew Waterfall	Nakorn Si Thammarat	08°29' N, 99°45' E/ 110 m a.s.l.	Bedrock predominant at above, pool in the middle with sand, cobble and gravel at below
S14	Prom Loke Waterwall	Nakorn Si Thammarat	08°31' N, 99°46' E/ 138 m a.s.l.	Bedrock predominant at above, deep pool in the middle with sand and silts, cobble and gravel at below
S15	Yord Leung Waterfall	Nakorn Si Thammarat	08°38' N, 99°44' E/ 78 m a.s.l.	Large boulders and cobble predominant, small deep pool in the middle, cobble, gravel and sand at below
S16	Ei Kaew Waterfall	Nakorn Si Thammarat	08°33' N, 99°46' E/ 127 m a.s.l.	Bedrock and boulders predominant at above, deep pool in the middle, cobble, gravel and sand at below
S17	Sunantha Waterfall	Nakorn Si Thammarat	08°46' N, 99°48' E/ 166 m a.s.l.	Bedrock and boulders predominant at above, deep pool in the middle, cobble, gravel and sand at below

Table 1.1 Continued.

S18	Kachong Waterfall	Trang	07°32' N, 99°47' E/ 59 m a.s.l.	Large boulders and cobble predominant, small deep pool in the middle, cobble, gravel and sand at below
S19	Praiwan Waterfall	Patthalung	07°21' N, 99°57' E/ 73 m a.s.l.	Bedrock and boulders predominant at above, deep pool in the middle, cobble, gravel and sand at below
S20	Mom Jui Waterfall	Patthalung	07°15'N, 100°02' E/ 95 m a.s.l.	Bedrock and boulders predominant at above, deep pool in the middle, cobble, gravel and sand at below
S21	Ranee Waterfall	Satun	06°42' N, 100°10' E/ 94 m a.s.l.	Bedrock and boulders predominant at above, cobble, gravel and sand at below
S22	Yaroi Waterfall	Satun	06°45' N, 100°09' E/ 66 m a.s.l.	Bedrock and boulders predominant at above, small deep pool in the middle, cobble, gravel and sand at below
S23	Ton Nga Chang Waterfall	Songkhla	06°56' N, 100°14' E/ 53 m a.s.l.	Bedrock and boulders predominant at above, deep pool in the middle, cobble, gravel and sand at below
S24	Sirindorn Waterfall	Narathiwas	05°48' N, 101°49' E/ 62 m a.s.l.	Bedrock and boulders predominant at above, small deep pool in the middle, cobble, gravel and sand at below

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Figures 1.3-1.8. 1.3, stream from Haew Lome Waterfall; 1.4, Bok Krai Waterfall; 1.5, Ngao Waterfall; 1.6, Klong Bang Mun Stream; 1.7, Mae Yai Waterfall; 1.8, stream from Sib Ed Chan Waterfall.

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Figures 1.9-1.14. 1.9, stream from Dad Fah Waterfall; 1.10, stream from Ton Thon Toey Waterfall; 1.11, stream from Huai To Waterfall; 1.12, stream from Si Khit Waterfall; 1.13, stream from Yong Waterfall; 1.14, Pliew Waterfall.

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Figures 1.15-1.20. 1.15, stream from Prom Loke Waterfall; 1.16, stream from Yord Leung Waterfall; 1.17, stream from Ei Kaew Waterfall; 1.18, stream from Sunantha Waterfall; 1.19, stream from Kachong Waterfall; 1.20, stream from Praiwan Waterfall.

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Figures 1.21-1.24. 1.21, stream from Mom Jui Waterfall; 1.22, Ranee Waterfall; 1.23, stream from Ton Nga Chang Waterfall; 1.24, stream from Sirindorn Waterfall.