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SMALLHOLDER AGRICULTURE DEVELOPMENT PROJECT (SADP)

Impact of Oil Palm on Freshwater Streams in Oro and West New Britain Provinces

Douglas Environmental Services

Port Moresby
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CONTENTS

Summary

Project and Client

The oil palm industry provides a major source of income for the West New Britain and Oro Provinces of Papua New Guinea. The Oil Palm Industry Corporation (OPIC) contracted Douglas Environmental Services to investigate the effects of smallholder activities on the environment. This project was funded by the World Bank as part of a Smallholder Agricultural Development Programme (SADP). Douglas Environmental Services contracted Landcare Research New Zealand Ltd to assess the effects of smallholder oil palm activities on the biology of West New Britain and Oro Province streams.

Objectives

The objectives of this project are to:

- assess current and potential effects of smallholder oil palm operations on stream habitat and biota,
- recommend methods of minimising adverse effects, and
- demonstrate a method for assessing any adverse effects on stream ecosystems.

Methods

Landcare Research and Douglas Environmental Services assessed the habitat quality and aquatic biota of streams in the West New Britain and Oro Provinces during June–July 2006. Study sites were selected with the assistance of OPIC personnel to provide data from streams draining oil palm areas, and streams draining secondary native forest. Freshwater invertebrates were used as the primary indicators of habitat and water quality, but physical habitat details, temperature and dissolved oxygen were also recorded to aid interpretation.

Invertebrates were identified as far as possible in the field, and specimens were taken to Landcare Research in Auckland New Zealand for more accurate identification and for microscope photography. Invertebrate results were interpreted with the aid of published literature and internet resources relevant to the region.

Results and Discussion

Smallholder oil palm activities have been found to affect stream systems in many ways, particularly:

- Land clearance for future oil palm plantations, causing loss of native biodiversity and terrestrial food inputs to streams, increased erosion and stream sedimentation, loss of shade (allowing stream warming) until oil palms are large enough to provide shade, and drying of wetland areas and small streams.
- Increased road construction and road damage during land clearance and oil palm maintenance, resulting in increased sediment runoff, increased use of (and failure of) bridges and culverts, and the creation of fish barriers at poorly designed culverts.

- Increase in human population in oil palm areas resulting in instability of riparian margins (as stream banks are used for gardens), pollution by domestic waste disposal and by the use of bleach when washing in streams, and increased fishing pressures.
- Possible chemical effects (though not observed during this study) through fertilisers entering streams via surface runoff or via groundwater entering streams, and accidental spillages of herbicides, or pesticides (though poisoning is apparently well controlled by OPIC).

While there are likely to be changes in the composition of stream communities following conversion from forest to oil palm land use, this study found that oil palm streams can support similar aquatic communities to forest streams, and no examples of badly polluted streams were found in established oil palm areas.

Protecting streams from the effects of smallholder oil palm activities can be achieved through a range of methods, including:

- **Location of new oil palm areas.** Locating new oil palm plantations in areas of existing poor quality vegetation, and in areas already serviced by roads.

- **Road construction and maintenance.** Construction and maintenance of stable roads, bridges and culverts that can withstand the vehicles used in the oil palm industry. Ensuring new bridges and culverts do not create barriers to fish migration.

- **Protecting buffer zones.** Maintaining buffer zones (as per OPIC guidelines) between new oil palm plantations and streams.

- **Safe use (or avoiding use) of chemicals.** Monitoring smallholder use of chemicals, and avoiding the use of herbicides around drains, streams and wetlands. Storage of agricultural chemicals where they can not be washed into watercourses.

Conclusions

Most of the West New Britain and Oro province oil palm streams inspected during June–July 2006 supported an abundance of freshwater invertebrate life, including a typical range of taxa for tropical Asian soft-bottom streams. These streams are important to people in both provinces for water supply, washing and fishing purposes.

Probably the most effective method of minimising the adverse effects of changes in land use on stream ecosystems is the protection of native vegetation along stream margins. The current OPIC riparian management guidelines (maintaining 10m, 50m or 100m buffer zones depending on stream type) should provide adequate protection for stream ecosystems. The on-going education of workers and residents in oil palm areas, regarding riparian protection, the safe disposal of domestic waste, and the appropriate handling of fertilisers and herbicides is also recommended, given that these people depend on streams for their own water supply.

Long term stream biological monitoring, using freshwater invertebrates as the primary indicators, should be undertaken to assess the effects of oil palm activities on stream ecosystems. This survey has produced baseline data that can be used for comparison with future biological monitoring results.

1.0 Introduction

The oil palm industry provides a major source of income for the West New Britain and Oro Provinces of Papua New Guinea. The Oil Palm Industry Corporation (OPIC) contracted Douglas Environmental Services to investigate the effects of smallholder activities on the environment. This project was funded by the World Bank as part of a Smallholder Agricultural Development Programme (SADP). Douglas Environmental Services contracted Landcare Research New Zealand to assess the effects of smallholder oil palm activities on the quality of West New Britain and Oro Province streams.

Using invertebrates as indicators of the condition of stream water and habitat quality

Aquatic invertebrates are key components of stream ecosystems. The aquatic larvae of many insects, aquatic crustacea, molluscs, and worm-like groups usually dominate these communities. Stream invertebrates include shredders that break down leaf litter from terrestrial vegetation, grazers that feed on aquatic algae and plants, filterers that feed on fine organic particles and predators that feed on other invertebrates (sometimes fish). Many species require flowing waters with high levels of dissolved oxygen, while others can thrive in polluted, oxygen-poor waters. Some species require stony or woody substrata for attachment, while others can burrow into soft sediments. With an understanding of the habitat requirements of the different invertebrate groups, ecologists can learn much about the physical, chemical and biological condition of stream habitats.

Invertebrates are the most commonly used freshwater biological indicators in monitoring programmes designed to assess the state of rivers and streams. They are typically abundant on streambeds or amongst submerged vegetation, and they are usually easy to sample. Identification of most groups to family level is relatively easy, and in some areas keys have been developed allowing identification to genus or species levels. While there has been limited research on the aquatic invertebrates of many tropical Asian areas (Dudgeon, 1999) and limited work on the taxonomy of Papua New Guinea freshwater invertebrates, it was possible to identify most "taxa" (or types) to at least to family level.

Many aquatic invertebrate groups are relatively sessile, living in the same reach of a stream throughout all or most of their lives, and therefore they can be useful long-term indicators of the habitat quality and water quality of that reach. They provide an indication of the likely food availability for fish because most freshwater fish species feed on aquatic invertebrates. This is particularly important in the tropics where people often "live off the land" and streams providing fisheries are highly prized. Many streams may provide physical habitats capable of supporting large fish populations but the availability and quality of invertebrate food sources may limit the fish growth rates and population size.

Stream invertebrates can also be important in the diets of many terrestrial invertebrates. Spiders are very common along the margins of streams because of the richness of invertebrate prey, including the flying adults of stream mayflies, caddisflies, damselflies, dragonflies, craneflies, midges and many other types of flies with aquatic larvae. Tetragnathid spiders for example, often construct horizontal webs over stream channels to catch the flying adults of stream insects. Such terrestrial invertebrates become food for other invertebrate predators and birds.

Sampling and analysing stream invertebrates is an essential component of studies relating to the condition of aquatic and stream margin ecosystems. These ecosystems can be adversely affected by many land use practices, especially if such practices damage riparian (bank-side) vegetation or if they pollute streams with excessive levels of sediment, organic waste, heavy metals of other toxins. Agricultural activities such as the replacement of regenerating native forest with oil palm plantations could potentially damage riparian vegetation, cause sedimentation of streambeds, and change stream water quality.

This World Bank funded project relates particularly to the effects of smallholder oil palm operations on the environment. The project is designed to:

- assess current and potential effects of smallholder oil palm operations on stream habitat and biota,
- recommend methods of minimising adverse effects, and
- demonstrate a method for assessing any adverse effects on stream ecosystems.

2.0 Methods

Landcare Research and Douglas Environmental Services assessed the habitat quality and aquatic biota of streams in the West New Britain and Oro Provinces during June–July 2006. Study sites were selected (with the aid of local oil palm industry personnel) to provide data from streams draining areas of oil palm plantations, and streams draining secondary forest (representing a pre-oil palm condition). The sites assessed during the current investigation are illustrated in Figures 1 and 2. Location and habitat details recorded at each site included:

- GPS coordinates,
- altitude,
- riffle, run or pool habitat (photographed with a digital camera),
- bed composition,
- temperature,
- dissolved oxygen,
- riparian (bank-side) vegetation and shade, and
- surrounding landuse.

Freshwater invertebrates (primarily from the streambed, but some from the stream surface and stream margins) were used as the primary indicators of habitat and water quality, but any fish or amphibia caught were also recorded.

Freshwater invertebrate samples were collected with a pole net (0.5-mm mesh) using the "kick sampling" method at stony riffle sites, and the "sweep sampling" at slow-flowing, soft-bedded sites. Kick sampling and sweep sampling methods involve disturbing the streambed by foot or with a sampling net, and collecting organic material in the net using the stream flow or by sweeping the net through the water. Flowing sites with hard or stable substrata were selected where possible, because such sites provide the most diverse invertebrate communities, and therefore the most information about the "life supporting capacity" of a stream reach.

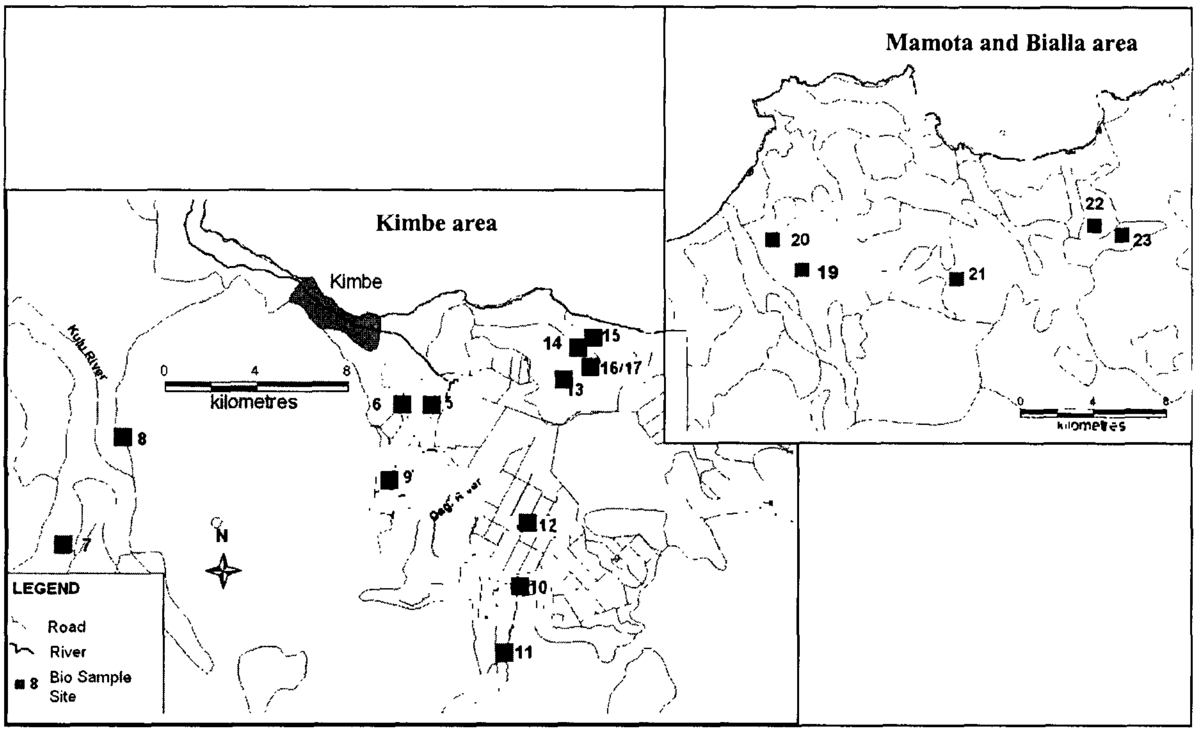


Figure 1: Sampling sites in the West New Britain Province, June 2006. Maps supplied by Douglas Environmental Services. Sample site numbers correspond with the site numbering in Appendix 2. Note – sites 1 to 4 were located around Port Moresby (not part of this study).

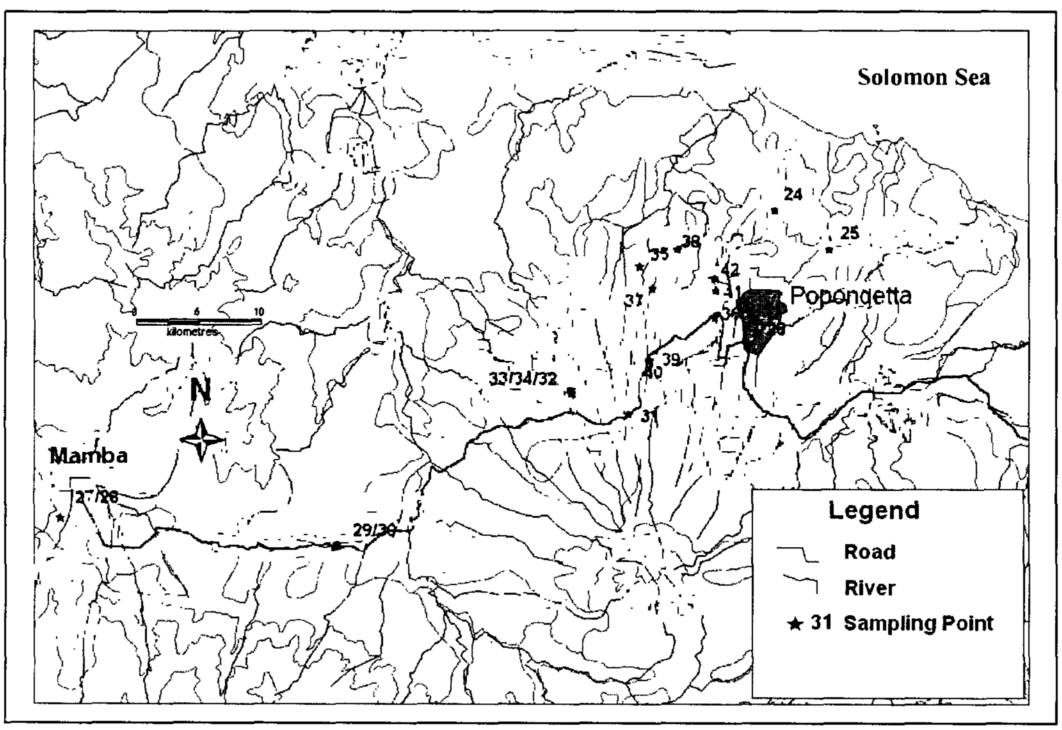


Figure 2: Sampling sites in the Oro Province, July 2006. Map supplied by Douglas Environmental Services. Sample site numbers correspond with the site numbering in Appendix 2. Note – sites 5 to 23 were located in West New Britain.

Sampling involved collecting streambed material using a pole net with 0.5-mm mesh.	The sample was placed in a tray from which invertebrates were removed for further analysis.

Figure 3: Stream biological sampling methods.

Where there was a range of suitable sampling sites in a stream reach, the most common habitat type was chosen (representative of the stream reach). These sampling methods were based on the New Zealand protocols for sampling macroinvertebrates in wadeable streams (Stark et al. 2001) which are available on the web page: http://www.mfe.govt.nz/publications/water/macroinvertebrate-protocols-wadeable-streams-nov01.html

In the current project, most invertebrate sorting was carried out in sorting trays (Fig. 3) in the field, rather than in the laboratory (a departure from the above protocols) because of time and budget constraints. Sampling was therefore aimed at collecting an amount of solid material (approximately 200 ml) that could easily be scanned in the sorting tray. Invertebrates found in the tray were recorded using the abundance codes:

1 = rare (single individual in the tray),
2 = common (2 to 10 individuals in the tray),
3 = abundant (10 to 20 individuals in the tray) and
4 = very abundant (more than 20 individuals in the tray).

Specimens of all taxa found in the tray were taken to Landcare Research in Auckland, New Zealand, for more accurate identification (most commonly to family) and for microscope (Automontage) photography (Appendix 1). Invertebrate results were interpreted with the aid of published literature and internet resources relevant to the region, particularly:

- a major review of the tropical Asian freshwater invertebrates in Dudgeon (1999);
- a guide to Australian freshwater invertebrates in Gooderham and Tsyrlin (2002);
- a guide to Singapore freshwater invertebrates in Ng (1992);
- "Lucid" Keys to Australian invertebrates available on the internet (http://www.lucidcentral.com/keys/lwrrdc/public/Aquatics);
- keys to New Zealand aquatic insects in Winterbourn et al. (2006).

The full lists of taxa recorded in the two provinces during this study are shown in Appendix 2.

3.0 Results and Discussion

3.1 Potential and observed environmental effects of oil palm activities

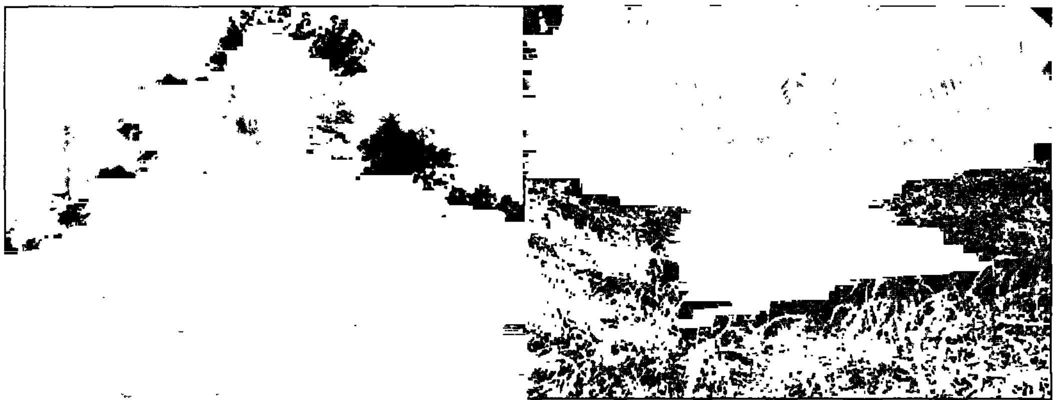
Smallholder oil palm activities can affect stream systems in many ways. The following sections summarise effects observed in June–July 2006, and anecdotal accounts from people interviewed in the West New Britain and Oro Provinces. The main effects of smallholder oil palm activities appear to relate to four main categories: land clearance, road construction (and maintenance), human population increases, and the use of agricultural chemicals.

Land clearance for oil palm

The clearance of native forest or wetland vegetation cover to make way for oil palm plantations will have many effects on terrestrial and freshwater ecosystems. While it appears that generally only secondary (not primary or pristine) forest is cleared to make way for smallholder oil palm plantations, the biodiversity values of such forest or wetland areas could be considerable and the subject of a major terrestrial botanical and zoological study. This World Bank project, however, primarily relates to impacts of smallholder activities on streams.

The main impacts of land clearance for agriculture on stream ecosystems observed in other parts of the world often include:

- loss of native food sources, loss of aquatic habitat complexity, and loss of native riparian habitat required by the flying adults of some stream invertebrates,
- loss of groundcover worsening erosion and stream sedimentation in cleared areas,
- warming of streams following forest clearance before oil palm plants are large enough to provide shade (Fig. 4),
- plantations of introduced crops including oil palm may provide less terrestrial invertebrate food for aquatic species (compared with native vegetation),
- wetlands and small streams may dry up following drainage works in preparation for new plantations (Fig. 4), and
- introduced crops including oil palms may extract more shallow groundwater than native forest, further increasing the risk of the drying of nearby wetlands and small streams.



Forest clearance near the Tili Plantation, West New Britain.

Drain digging in oil palm areas can result in the loss of wetlands and streams. Beuru block, Oro.

Figure 4: Forest clearance and wetland drainage pressures relating to oil palm development.

Increase in road construction and wear

Roads are currently being constructed by the oil palm industry and in some cases by smallholders themselves. While there is a general policy of planting new areas of oil palm in areas already serviced by roads, brand new roads were observed under construction during this project (Fig. 5). Road wear (deterioration) was a serious issue in the West New Britain and Oro Provinces and this is a major problem for the industry (Ian Orrell, OPRA, pers. comm.).

The main impacts of road construction and road wear observed in oil palm areas in the two provinces were:

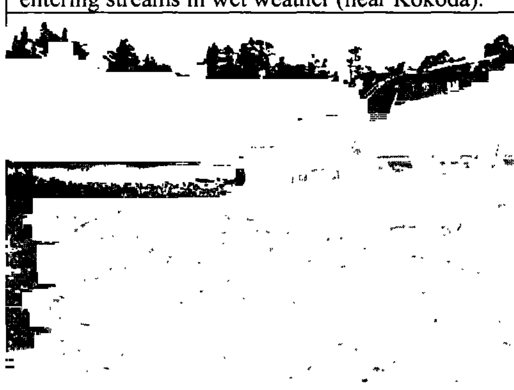
- the construction of new roads involves clearance of vegetation, exposing large areas of soil and creating the potential for large amounts of sediment runoff into streams (Fig. 5),
- unsealed roads and fords (Fig. 5) rather than culverts/bridges are sometimes heavily used during land clearance and oil palm harvesting, resulting in sedimentation of streams,
- many sealed roads have not been maintained and over time have broken down, allowing sedimentation of nearby streams,
- generally no treatment devices (such as sediment traps, catch pits, settling ponds grassy swales or filter walls) are used to prevent sediment running off roads and entering streams,
- gravel extraction (for road construction) often occurs along stream margins (Fig. 5) and the extraction sites can be major sources of sedimentation,
- the installation of road culverts also disturbs much sediment (that can smother downstream habitats) as well as creating barriers to the migration of fish (Fig. 6), and
- some poorly constructed bridges and culverts are at risk of deterioration and slumping (Fig. 6) causing sedimentation of streams.

Road construction near the Etere Stream, Oro Province.

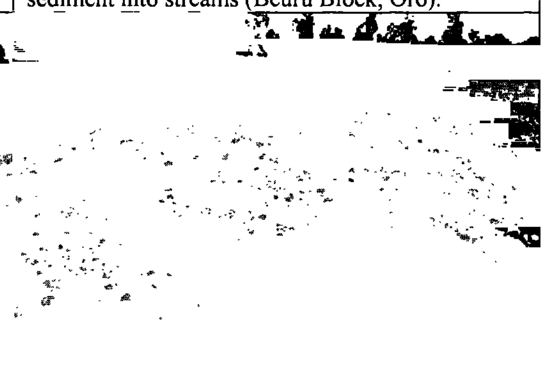
Same site as left, showing a stream crossing before culvert installation.

Unsealed roads result in large amounts of mud entering streams in wet weather (near Kokoda).

Unvegetated roadside drains allow rapid pulses of sediment into streams (Beuru Block, Oro).



Gravel extraction sites can cause significant sedimentation of streams (Rerengi, WNB).



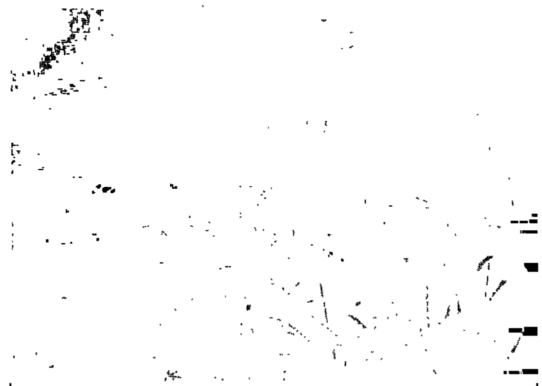
Streamside mud at a gravel extraction site will often be flushed into the river (Oro Province).

Figure 5: Road construction activities and road wear affecting stream habitats.

Newly installed culvert near the Etere Stream, Oro, showing sediment entering the stream.

Culvert water velocity and waterfalls at culvert outlets often create fish barriers (Gaungo, WNB).

Bridge and culvert collapse causes sedimentation of streams (near Isivini Stream, Oro Province).



Road material slumping into a stream at a culvert near the Beuru Block, Oro.

Figure 6: Culvert and bridge construction and deterioration affecting stream habitats.

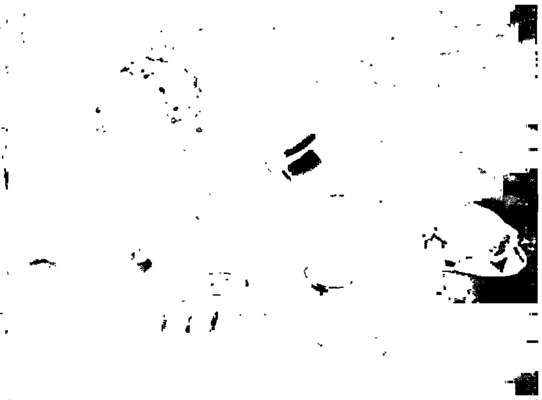
Increase in human population in oil palm areas

Some smallholder oil palm areas are not only plantations but also homes for people working in the plantations. Many small settlements were observed in both the West New Britain and Oro Provinces. These settlements typically consist of a small number of houses made from locally available wood, bamboo and often with thatched walls and roofs. Generally these houses have no electricity, no running water (other than a nearby stream) and only pit latrines (no sewage treatment facilities).

The potential impacts of the human populations on streams within the oil palm areas are likely to include:

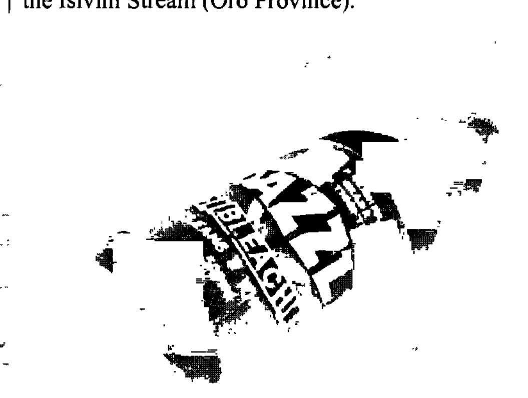
- instability of stream margins as people living in oil palm areas clear stream bank vegetation to make way for gardens (Fig. 7),
- waste disposal practices may be poor in some areas (use of pit latrines is common, but some people will use watercourses as a toilet),
- use of streams for washing clothes and cooking utensils (using bleach) increases as the human population increases (Fig. 7), and
- there is anecdotal evidence of increasing fishing pressures on streams as the human population increases.

Garden maintained to the waters edge in an oil palm area (near Lakimata, WNB).



Washing of cooking utensils in the midreaches of the Isivini Stream (Oro Province).

Washing of clothes, cooking utensils and children in the lower Isivini Stream (Oro Province).



Empty bleach bottles are commonly seen downstream of road bridges (Gaungo, WNB).

Figure 7: Likely effects of human population growth on stream habitats in oil palm areas.

Possible agricultural chemical contamination

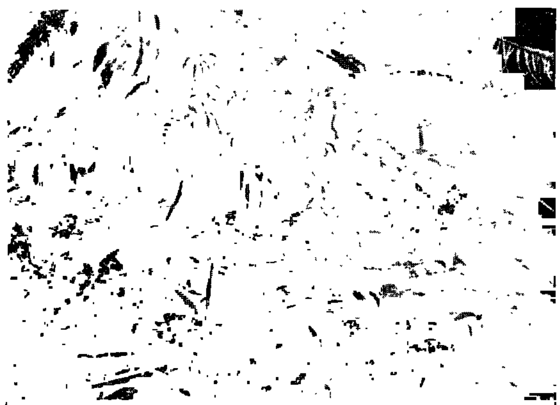
The PNG oil palm industry generally does not require large quantities of agricultural chemicals other than nitrogen fertilisers and weed sprays (Ian Orrell, OPRA, pers. comm.). Smallholders generally use less nitrogen fertilisers than the large oil palm companies and the fertilisers are generally applied by hand around individual palms. The distribution of herbicides is controlled by OPRA and all spray operators must complete a training course on appropriate handling and use of herbicides. Weed sprays are generally applied by back-pack sprayers, again aiding accurate delivery. Animal pests are not usually a major problem, and the main invertebrate pests (tettigoniid grasshoppers and the phasmid stick insect *Eurycantha calcarata*) are being controlled with biocontrol agents and targeted palm trunk injection techniques. Rats are a problem in some areas and localised poisoning is required.

The potential adverse impacts relating to agricultural chemical use in oil palm areas appear to be:

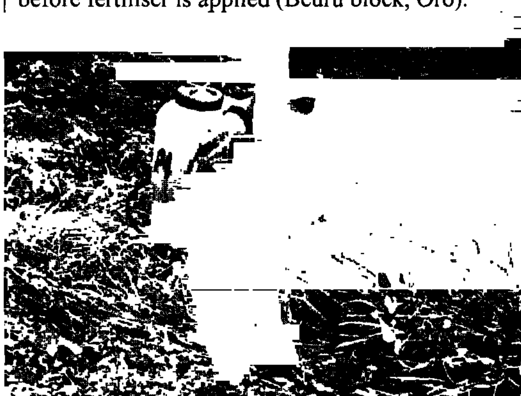
- fertiliser loss to shallow groundwater can enter streams (surface runoff was not observed in this study),

- some smallholders are slow to apply fertilisers after delivery of fertiliser bags, allowing the possibility of bag breakdown and leaching of fertilisers into drains or areas that could be flooded (Fig. 8),
- potential for herbicides to enter watercourses via drains or small streams along roads and between young oil palms (where most spraying occurs),
- some pest poisoning (particularly for rats) may kill native species,
- poisoning for invertebrate pests may occur, though OPIC favours biocontrol methods, not pesticides,
- poisons are used to kill old oil palms (though this is controlled by OPIC).

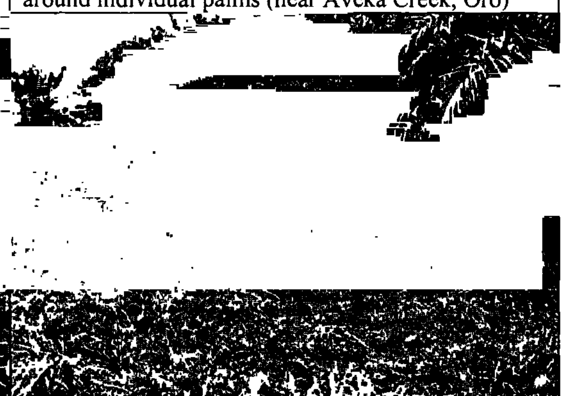
Fertiliser bags are sometimes left a long time before fertiliser is applied (Beuru block, Oro).



Fertilisers (white granules) are applied by hand around individual palms (near Aveka Creek, Oro)



Weed sprays are applied by hand by qualified spray operators (near Isivini Stream, Oro).



Most weed spraying occurs along roads and around the bases of young palms (near Rerengi, WNB).

Figure 8: Agricultural chemical use in oil palm areas.

3.2 Temperature and dissolved oxygen in oil palm and native bush streams

Temperature and dissolved oxygen levels were recorded at most sampling sites during this study. Both are important water quality factors affecting stream ecosystems. Shade and altitude affect stream temperatures, while temperature, depth, current and organic matter affect dissolved oxygen levels. Increasing temperature increases metabolic rates (and demand for oxygen) but increasing temperature also decreases the solubility of oxygen in water. As a general rule, a wider range of stream life can exist in cooler waters with higher dissolved oxygen levels.

Generally, native forest sites had cooler water temperatures (average 21.3°C) than oil palm sites (average 23.3°C), although there was considerable overlap in temperature ranges (Fig. 9). Native forest streams tended to have more complete shade, with less road clearings.

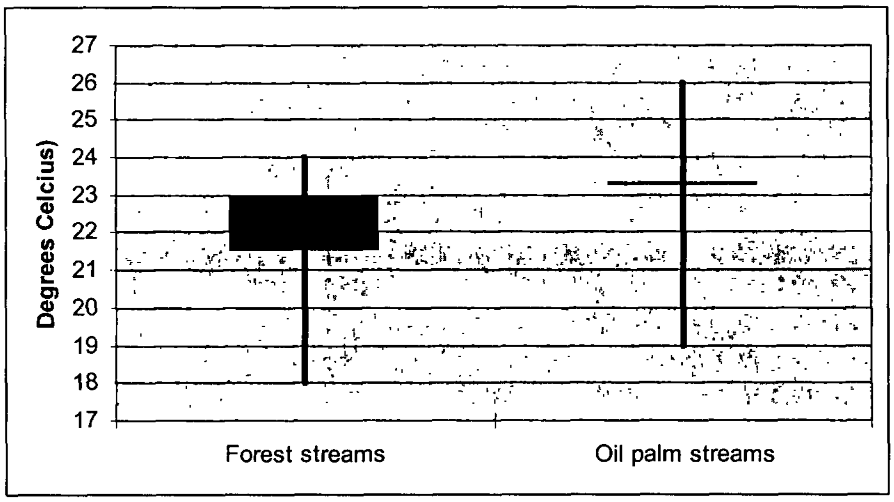


Figure 9: Water temperatures in native forest and oil palm streams. The vertical line shows the range of temperatures and the horizontal bar contains the average and median temperatures.

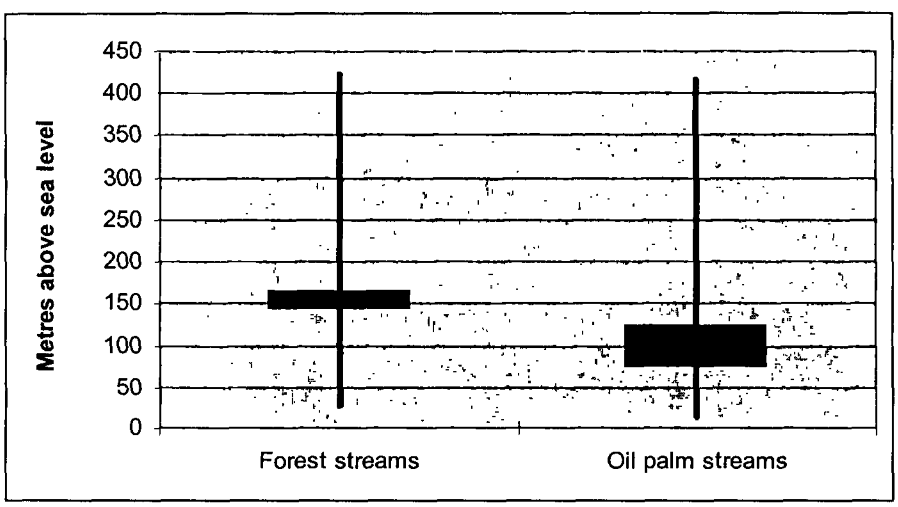


Figure 10: Altitudes recorded at native forest and oil palm stream sites. The vertical line shows the range of altitude and the horizontal bar contains the average and median altitudes.

Native forest sampling sites were often located a few hundred metres upstream of oil palm sampling sites, but there was no significant difference in altitude ranges for the two groups of streams (Fig. 10). The more complete shade of the forest stream reaches (rather than the slightly higher altitudes) will account for the cooler temperatures of the native forest sites.

The cooler temperatures of the forest sites would also be part of the reason for the higher dissolved oxygen levels (average 9.2 mg/L) than those recorded in oil palm streams (average 7.1 mg/L, Fig. 11). Generally the forest sites were located closer to the steeper headwater reaches where water currents tend to be faster, streams shallower, and physical aeration of streams occurs more readily.

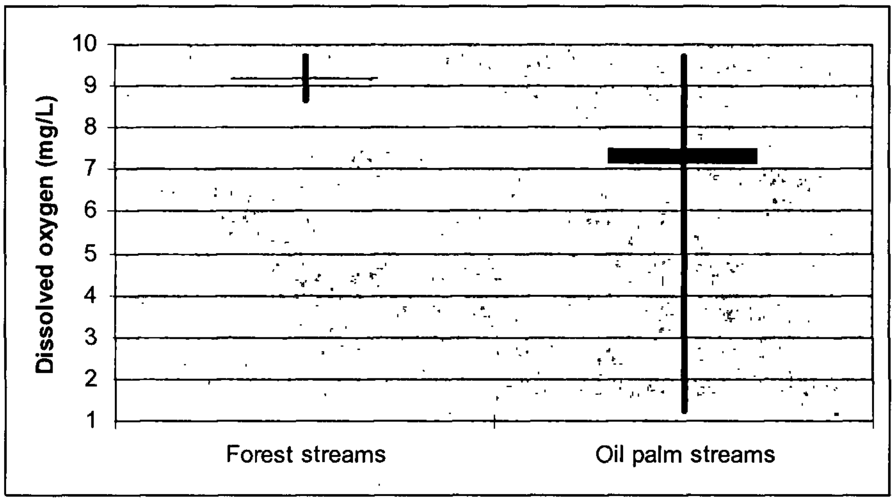


Figure 11: Dissolved Oxygen (DO) levels in native forest and oil palm streams. The vertical line shows the range of DO and the horizontal bar contains the average and median DO.

These differences between forest and oil palm streams (in altitude, temperature, gradient and dissolved oxygen) need to be considered when comparing the invertebrate faunas from the two groups of streams, as discussed in the following sections.

3.3 The freshwater invertebrates of oil palm streams

Streambed biological samples were collected from 20 sites in small streams with catchments largely or entirely covered by oil palm plantations. This provided a relatively large dataset and covered a wide range of physical habitat types. Smallholder oil palms are most commonly planted on relatively flat land where the low gradient naturally results in slow-flowing streams with mud, sand or fine gravel beds. However, artificial pulses of fine sediment are likely to have been added to these streams during land clearance over past decades. Stream reaches with fine sediment beds were therefore the most common habitat types sampled in this study.

Invertebrates found in each sample were assigned semi-quantitative abundance codes (rare, common, abundant or very abundant) during field and lab sample analyses, and these codes were converted into scores: rare = 1, common = 2, abundant = 3 and very abundant = 4. These abundance scores were totalled for each invertebrate group, for all oil palm samples to provide a list of most commonly occurring invertebrates in the oil palm sites. These most common invertebrates are listed in Table 1.

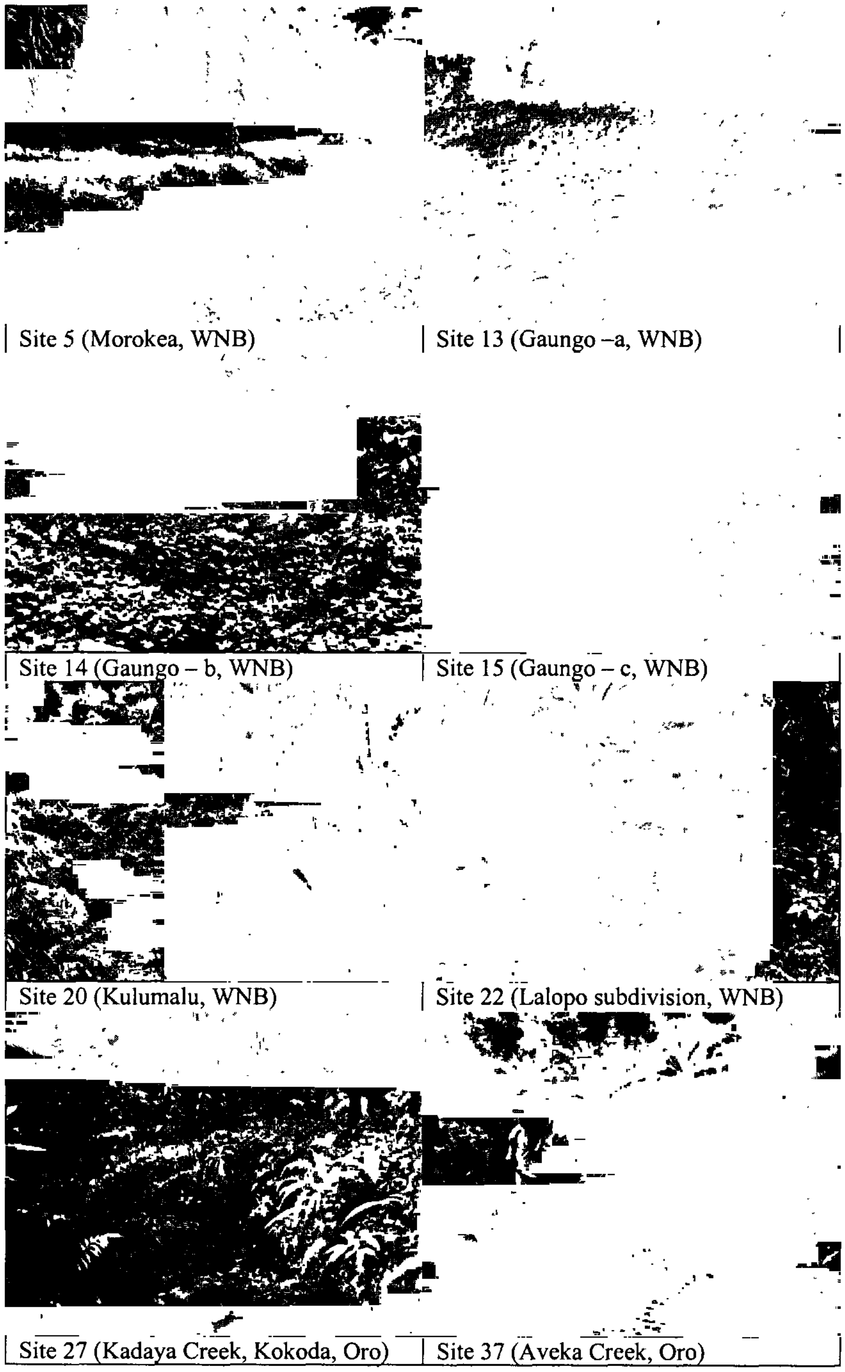


Figure 12: Examples of oil palm stream sites (see Table 1 for the most common freshwater invertebrate groups in such streams).

Table 1: Most abundant taxa in oil palm streams (from top of table):

1. Baetidae (swimming mayflies)
2. Libellulidae (dragonfly nymphs)
3. Hydropsychidae (net-spinning caddis)
4. *Platybaetis* type (Baetid mayflies)
5. Thiaridae (c.f. *Melanoides* snails)
6. Gerridae (water strider bugs)
7. Naucoridae (creeping water bugs)
8. Atyidae (shrimps)
9. Caenidae (swimming mayfly)
10. Brachiura (non-spider crabs)
11. *Triplectides* (stick caddis)
12. *Chironomus* (Chironomini midge)
13. *Polypedilum* (Chironomini midge)
14. Ostracoda (seed shrimps)
15. Hydrachnida (non-swimming mites)
16. *Oecetis* (Leptocerid caddis)
17. Simuliidae (black fly larva)
18. Tetrigidae (semi-aquatic grasshopper)
19. Protoneuridae (damselfly nymphs)
20. Pyralidae (aquatic caterpillars)
21. Hymenosomatidae (spider crabs)
22. Hydrachnida (swimming mites)

The following paragraphs discuss the ecology of the most common invertebrate groups found in oil palm streams. Examples of these taxa collected during this study, and notes on their typical habitats and potential indicator value are provided in Appendix 1.

Baetid mayflies (swimming mayflies with long antennae) were the most common invertebrate group in the oil palm stream samples. The baetids are very widespread in the tropical Asian region, especially in slow-flowing waters. Some baetids thrive in pristine waters, but others can tolerate highly polluted waters, making them a less useful group to use as pollution indicators without specialist taxonomic knowledge. A group of baetids with small or invisible terminal filaments (middle "tail") similar to *Platybaetis* or *Baetiella* were also common in oil palm streams (fourth most common group).

The libellulid family of dragonflies is very large, with larvae best represented in slow-flowing waters (most oil palm streams were slow flowing). Libellulids are known to be major predators of mosquito larvae and therefore their diversity and abundance may benefit the human population by helping limit the threat of malaria. Maintaining good populations of these long-lived dragonfly larvae may be achieved by maintaining year-round good water quality. A diverse libellulid fauna would suggest good habitat quality.

Hydropsychids are the most commonly encountered caddisflies in tropical Asian streams. Hydropsychids require firm substrata for attachment of their filter-feeding nets, and a regular supply of organic particulate matter (rather than inorganic sediment) for their food supply. As with the baetids, their presence does not necessarily indicate a particular water quality condition but rather a "typical" tropical Asian slow flowing stream fauna.

Thiarid snails include a number of species (possibly including those shown in Appendix 1) that have been introduced widely around the tropics, and their taxonomy is uncertain as shell shapes can be very variable. The group is known to occupy a wide range of habitats, but during this study thiarids were most abundant in shallow pools in oil palm streams.

Gerrid (water strider) bugs live on the water surface where they prey on other invertebrates. They are most common in slow flowing habitats, especially along the margins of streams. Being above the water they are not as directly affected by water quality as submerged species, but they are dependant on habitats of sufficient quality to support their prey. Predatory bugs were generally observed to be more common in good quality forest streams.

Naucorids (creeping water bugs) are predatory bugs that hunt for prey under the water surface (unlike the gerrids), particularly in slow-flowing waters (low gradient areas). The New Guinea naucorid fauna is described as endemic and particularly diverse by Dudgeon (1999) and they probably occupy a wide range of habitats. With such diverse groups, identification to species level and knowledge of species habitat associations would be required to determine their true value as indicators of water and habitat quality.

Atyid shrimps were particularly common along the weedy margins of slow flowing oil palm streams. Some atyids migrate between the sea and freshwater during their life cycles and their distribution can be limited by the presence of barriers such as waterfalls at culvert outlets (commonly observed during this study). These large invertebrates can be important food items for large freshwater fish species, particularly eels.

Caenid mayflies were found at about half of the oil palm sites and in most cases they were recorded as common. They are often found in slow-flowing sites with silty beds, which is a common habitat type in oil palm streams. Some species are quite tolerant of organic pollution and therefore the presence of caenid (or baetid) mayflies does not always indicate good water quality.

Freshwater crabs were the tenth most common invertebrate group in oil palm streams. Some crab species burrow into the stream bed or banks and would be hard to collect during sampling and therefore are likely to be under represented in this study. Different species may have entirely freshwater or partly marine life cycles, and they may have herbivorous, carnivorous or omnivorous diets. Some are largely confined to the water while others can spend long periods out of the water. Being larger invertebrates they are likely to be important food items for water birds and larger fish species.

Other invertebrate groups commonly found in oil palm streams, including leptocerid caddisflies, chironomid midges, ostracod seed shrimps, water mites and black fly larvae, are all common groups in tropical Asian streams.

This reflects a general observation with these oil palm streams, that the invertebrate fauna was dominated by groups that would be expected in slow-flowing, soft-bedded streams in the region. Sites located immediately downstream of a road construction site supported few invertebrates (as would be expected in any stream subjected to sudden influxes of sediment) but the stream fauna would be expected to recover as the streambed stabilises and re-colonisation occurs over time.

There may be streams polluted by domestic waste below human settlements in oil palm areas, and such sites may support invertebrate communities dominated by tolerant groups including syrphid flies, *Chironomus* midges and oligochaete worms. No such sites were found in oil palm areas during this study, but a syrphid fly pupa (photo in Appendix 1) was found in a Port Moresby stream below a sewage outlet.

3.4 Comparison between the invertebrates of oil palm streams and forest streams

Stream invertebrate samples were collected from 8 sites in streams with upstream catchments largely or entirely covered by native vegetation, allowing comparisons with the oil palm stream samples. Native vegetation sites were primarily small streams with the exception of Sites 7 (Galivau River, WNB) and 31 (Isivini Stream, Oro) which were a larger riffle sites. The remaining six native sites were located upstream of areas of oil palm plantations. While most forest stream sites (Fig. 13) were similar to the oil palm streams in terms of gradient, current and bed material, the forest sites were slightly higher in altitude, with slightly cooler and faster flowing water compared with the oil palm sites (Section 3.2). This is likely to have some influence on the invertebrate faunas of the forest streams.

The dominant invertebrate groups in the native forest stream samples are summarised in Table 2.

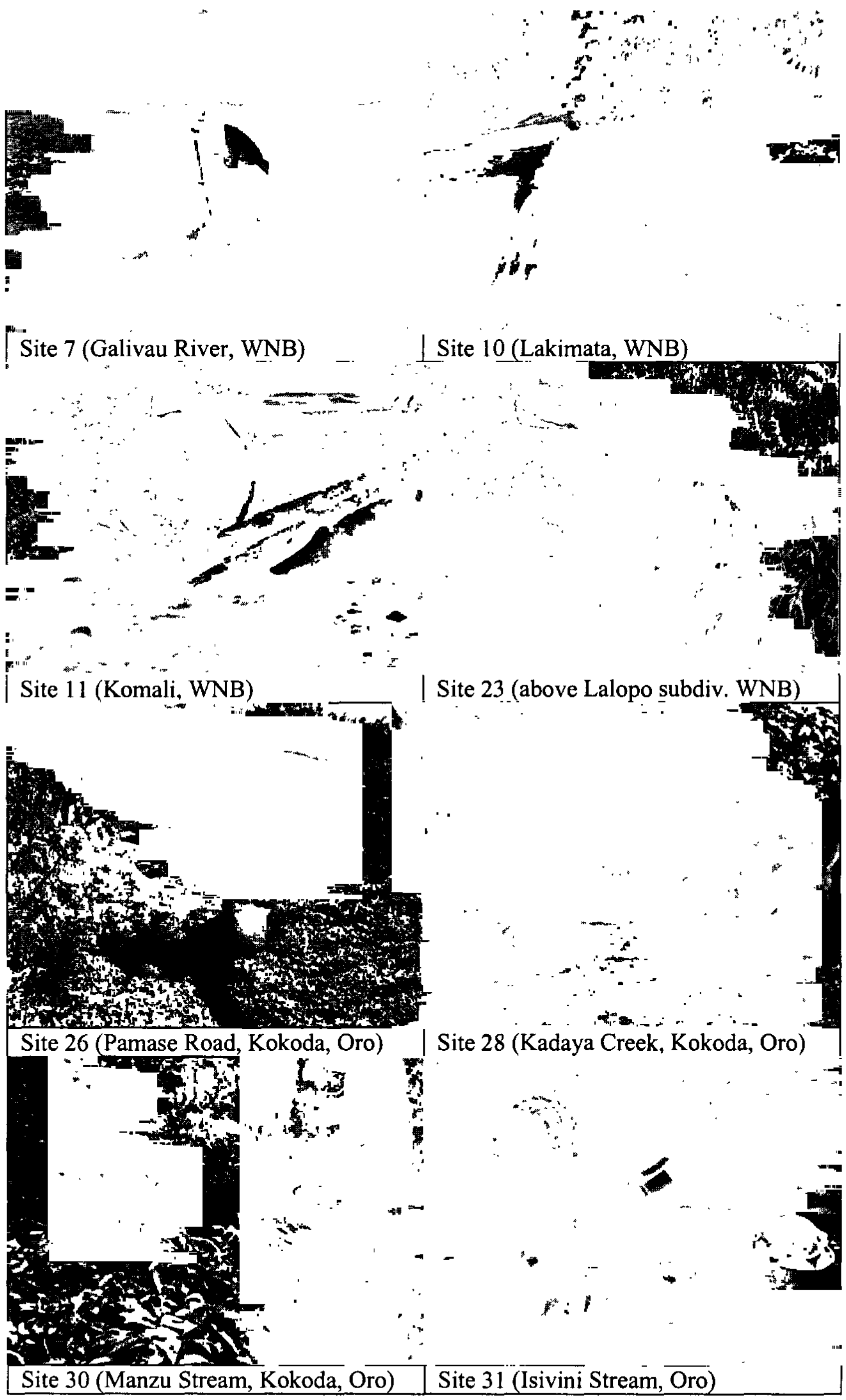


Table 2: Most abundant taxa in forest streams (from top of table):

1. Libellulidae (dragonfly nymphs)
2. Baetidae (swimming mayflies)
3. Hydropsychidae (net-spinning caddis)
4. Gerridae (water strider bugs)
5. Naucoridae (creeping water bugs)
6. *Triplectides* (stick caddis)
7. Philopotamidae (free living caddis)
8. Orthocladiinae (midge larvae)
9. Simuliidae (black fly larva)
10. Tanytarsini (Chironomini midge)
11. Pyralidae (aquatic caterpillars)
12. *Platybaetis* type (swimming mayflies)
13. Caenidae (swimming mayfly)
14. Elmidae (riffle beetles)
15. Atyidae (shrimps)
16. Brachiura (non-spider crabs)
17. Leptophlebiidae (mayfly nymph)
18. *Oecetis* (Leptocerid caddis)
19. Protoneuridae (damselfly nymphs)
20. *Rhagovelia* (riffle bugs)
21. Dytiscidae (diving beetles)
22. Muscidae (house fly larvae)

Figure 13: Examples of native forest stream sites (see Table 2 for the most common freshwater invertebrate groups in such streams).

The three most common invertebrates in the native forest streams, libellulid dragonflies, baetid mayflies and hydropsychid caddisflies, were also the three most common groups in the oil palm streams. Extensive taxonomic work would be required to determine whether the species found in the forest and oil palm sites are the same, but the appearance of the larvae suggests they are very similar.

Other similarities in the invertebrate faunas of the native forest and oil palm streams are reflected in the lists of commonly occurring taxa in Tables 1 and 2. Both lists include gerrid and naucorid bugs, leptocerid (*Triplectides*-like and *Oecetis*-like) caddisflies, caenid and *Platybaetis*-like mayflies, simuliid black flies, pyralid aquatic caterpillars, protoneurid damselflies, freshwater crabs and atyid shrimps. Of the 22 most common taxa in the forest streams (Table 2), 14 were also among the 22 most common taxa in the oil palm streams (Table 1).

Some of the differences between the invertebrate faunas of forest and oil palm streams may primarily relate to the slightly cooler water, faster flow and higher dissolved oxygen levels in the forest streams. Philopotamid caddisflies, elmid beetles, leptophlebiid mayflies and *Rhagovelia* bugs are all known to be common in fast flowing ("riffle") habitats, and they were all among the 20 most common groups in the forest streams (Table 2), but not among the 20 most common groups in the oil palm streams (Table 1).

The differences between forest and oil palm stream invertebrate communities were also assessed by comparing the frequency of occurrence of particular groups in these samples, regardless of abundance (Fig. 14). Many invertebrate groups were recorded in a higher proportion of the native forest stream samples than the oil palm stream samples. This was especially noticeable with the philopotamid and hydropsychid caddisflies, orthoclad and tanytarsini midges, simuliid black flies and libellulid dragonflies. These are very different groups with different niches, but the hydropsychids, philopotamids and black flies are filter feeders and they may benefit from the slightly faster flow, harder beds and more natural drifting food particles of the forest streams.

Some of the forest associated taxa are likely to be shredders (such as *Triplectides* caddisflies) that feed on native leaf litter. The orthoclad and tanytarsini midges and leptophlebiid mayfly species found most commonly in forest streams are likely to feed on fine organic layers on streambeds and they may be sensitive to changes in the composition/quality of these layers after the surrounding land cover changes from forest to oil palm. Naucorid and gerrid bugs and libellulid dragonflies are predators that may find a wider range of preferred prey (aquatic and terrestrial invertebrates) in forest areas.

Oil palm streams tended to have softer beds in part because of their naturally low gradient and slow flow, but possibly also because of additional sediment loading relating to the forest clearance of past decades. The midges and libellulids are large groups including many species associated with pristine habitats, but other species able to tolerate polluted waters.

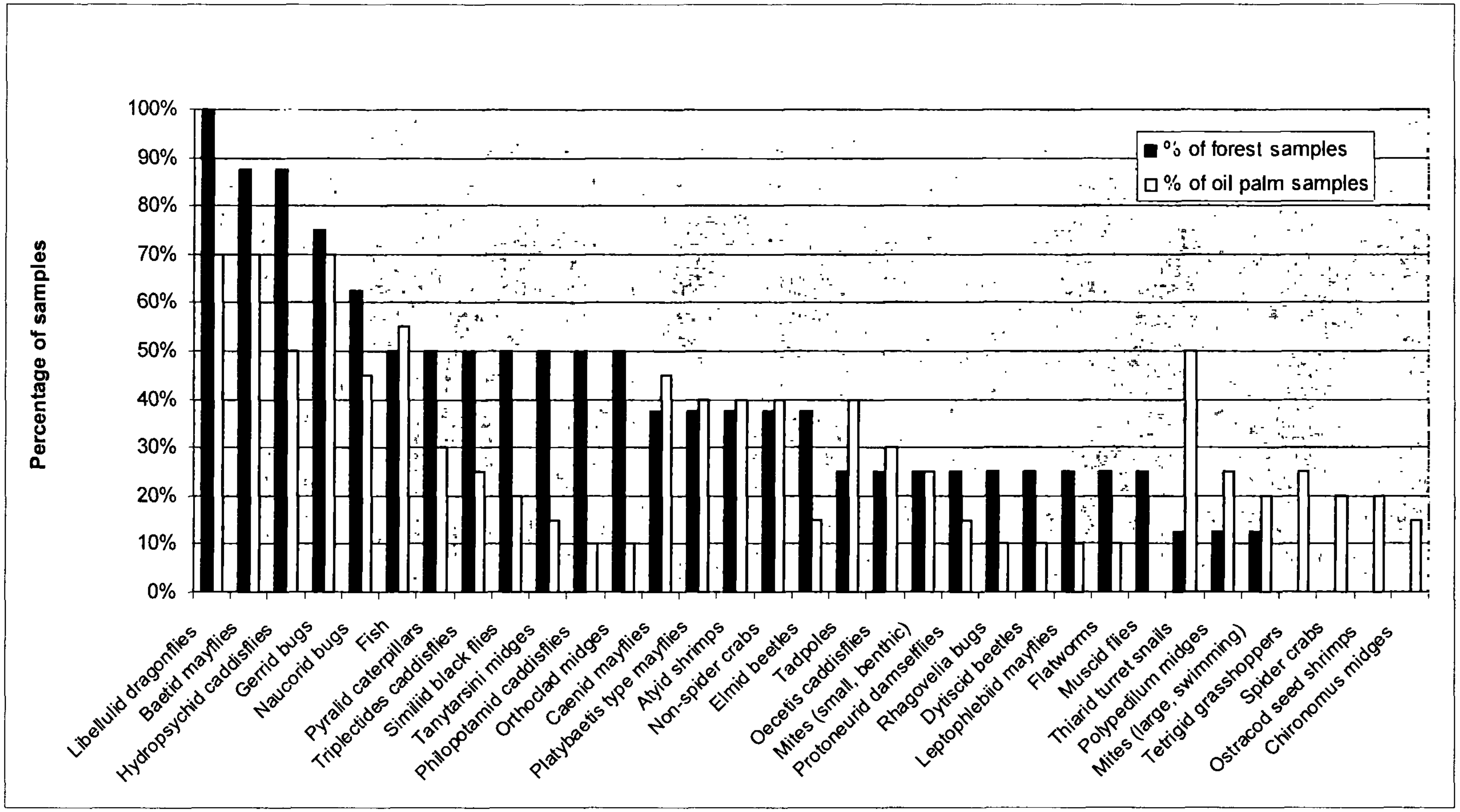


Figure 14. Frequency of occurrence of invertebrate groups in native forest and in oil palm stream samples

Groups found in a higher proportion of the oil palm streams than the forest streams included the thiarid snails, tetrigid aquatic grasshopper, spider crabs (hymenosomatids), ostracod seed shrimps and *Chironomus* midges. The thiarid snails and spider crabs are known to have been introduced to many parts of the tropics and their distribution could be related in part to the greater human presence in oil palm areas. Freshwater snails and crabs have been used by people in tropical Asia as a food source, but they can also be carried around accidentally in water containers or on fishing equipment.

Chironomus and ostracods are groups commonly associated with fine sediments in waters polluted by organic matter; however, they do not necessarily need such conditions to survive. The only streams found during this study that appeared to be significantly polluted by organic matter were those receiving oil palm mill effluent (discharges from outside of smallholder oil palm activities). The ability of *Chironomus* and ostracods to live on/in fine sediments and in waters with low dissolved oxygen makes them well suited to the slow-flowing, soft-bedded streams typical of low-gradient oil palm areas.

The tetrigid grasshoppers may be more commonly encountered in oil palm streams because they are suited to moist habitats with abundant algal growth, and such habitats are common in oil palm growing areas (Charles Dewhurst, OPRA, pers. comm.).

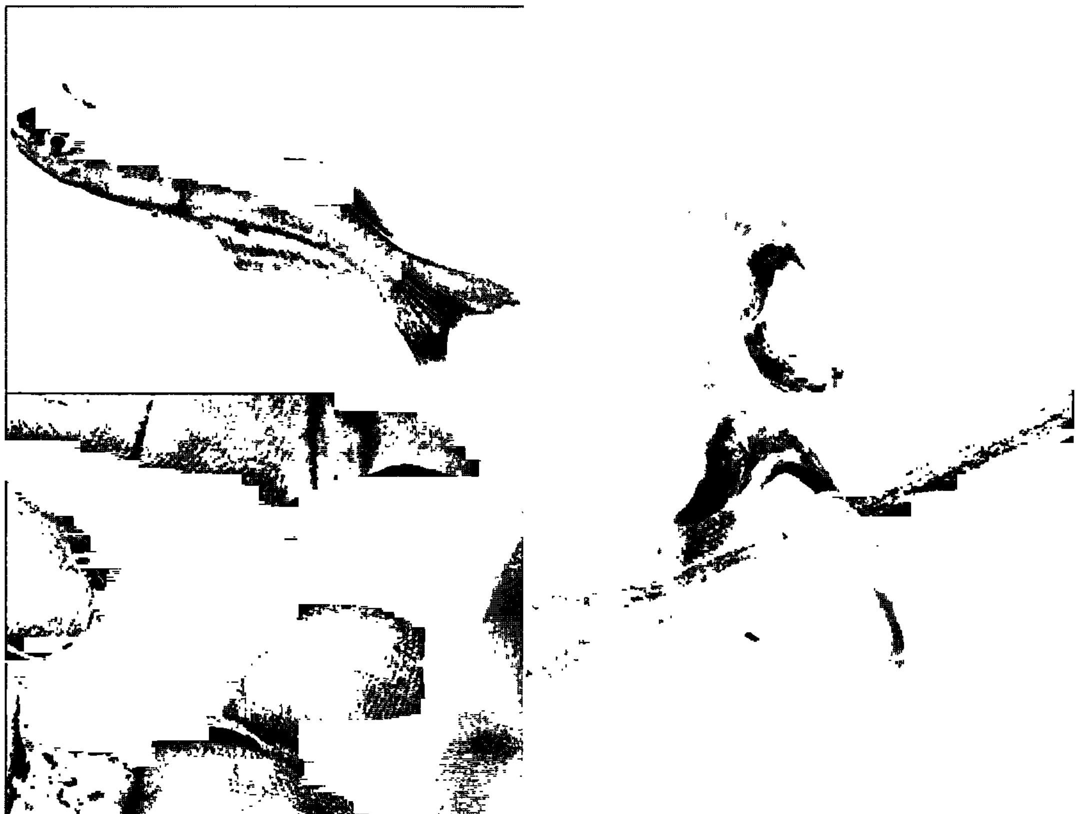
3.5 Fish and amphibia observed during this study

Papua New Guinea has approximately 330 species of freshwater fish, including a few introduced species. The native fish fauna has many similarities to the Australian fish fauna, reflecting the close proximity and past links between these landmasses. About 10% of the freshwater fish species found in PNG are also found in Australia. Approximately two thirds of the PNG native species spend their entire lives in freshwater and one third are thought to be have an estuarine or seawater stage in their life cycle (Allen 1991).

Allen (1991) summarised the freshwater fishes of New Guinea but this summary did not cover the fish fauna of West New Britain. It is likely, however, that future studies will reveal species that are endemic to West New Britain. Allen (1991) describes the fish fauna of Eastern Papua: northern section, which includes the Oro Province, as being relatively impoverished. The limited fauna may be in part due to the relative isolation from other provinces caused by the Owen Stanley Range. There are however, several species found only in this area.

While this study targeted stream invertebrates as the primary indicators of habitat quality, freshwater fish (Fig. 15) were recorded at approximately half the sampling sites in both forest and oil palm areas. Quantitative surveys of the distribution and abundance of fish species would require an intensive monitoring programme involving electric fishing and/or netting at many sampling sites; however, this survey illustrated that fish are common in oil palm streams.

There were anecdotal accounts from people working in West New Britain and Oro Province oil palm areas of local people fishing extensively in streams near their settlements, particularly streams running through oil palm areas. People in both provinces believed larger fish had become less common in recent years because of increased fishing pressures. This could make any study of the effects of landuse on fish populations difficult, because it may be hard to separate the impacts of fishing from the impacts of landuse on fish populations. During this study people were observed catching fish from the Isivini Stream in the Oro province (Fig. 15).

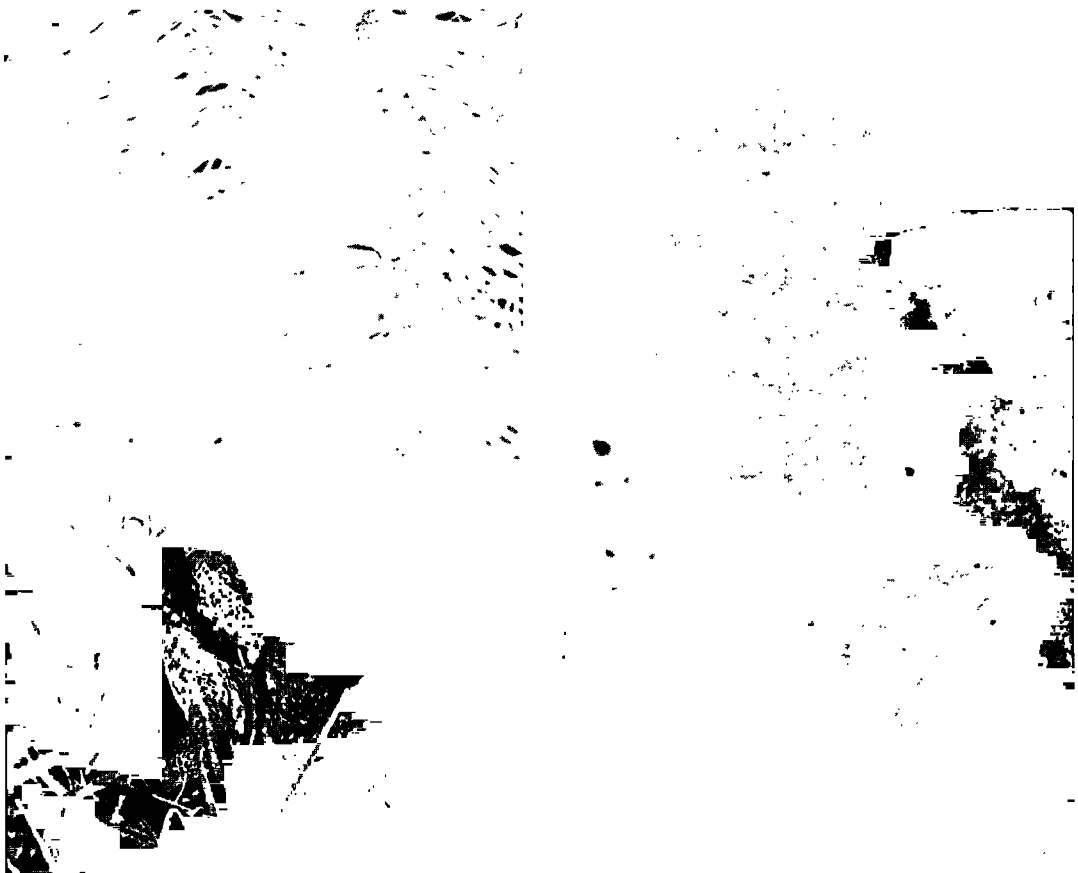


Top left, Popondetta rainbow fish, site 26 (Oro) Bottom left, an unidentified gobiid, site 24 (Oro)	Above, fish caught from the Isivini Stream by villagers, site 35 (Oro)

Figure 15. Examples of fish found during this study.

Frogs or tadpoles (Fig. 16) were also observed at several oil palm sites and a few native forest sites. Adult cane toads (*Bufo marinus*) were observed to be common in both provinces as they emerged after dark. The high abundance of black tadpoles, believed by locals to be juvenile cane toads (though this was not confirmed by experts) in several slow-flowing sites suggests this species could be affecting the population dynamics of native aquatic and terrestrial communities. A major study would be required to determine the extent of such effects and how these effects may vary with changes in landuse.

Cane toad tadpoles appear to colonise temporary habitats more successfully than other vertebrate species. These tadpoles were abundant in temporary pools created in depressions formed by vehicle tyre tracks (site 13) in the Gaungo area of West New Britain. Cane toad tadpoles are highly toxic to most animals, helping them to avoid predation in such exposed habitats. The invasive success of cane toads is also partly due to their opportunistic feeding strategy, being able to feed on a wide variety of food items, both living and dead.



Top left, cane toad tadpoles, site 13 (WNB) Bottom left, cane toad adult, Bialla (WNB)	Above, small frogs (unidentified species) were abundant in open gravel habitats, site 35 (Oro)

Figure 16. Examples of amphibia (tadpoles toads and frogs) found during this study.

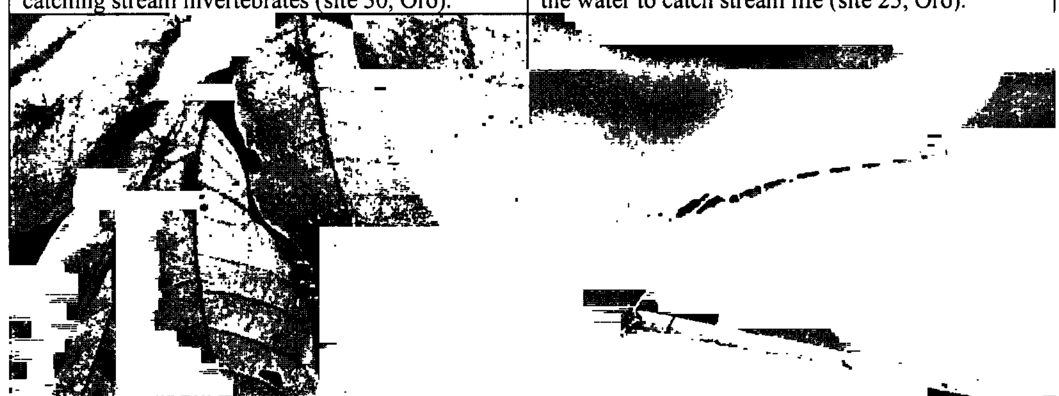
3.6 Terrestrial invertebrates observed during this study

A wide range of terrestrial invertebrate species were observed in both provinces, as might be expected given the tropical setting. The strong links between terrestrial vegetation and aquatic ecosystems are well known, but the interactions between terrestrial invertebrates and the aquatic fauna are also complex and important, for example:

- tetragnathid spiders (Fig. 17), which were observed at many sites in this study, often catch the adults of aquatic insects as they emerge from the water,
- *Dolomedes* spiders (Fig. 17) enter the water to catch stream invertebrates and fish,
- many terrestrial invertebrates live on vegetation around or over the water and they can form a significant part of the diets of freshwater fish,
- damselflies and dragonflies have aquatic nymphs, but their adults (Fig. 17), prey on other invertebrates including terrestrial species.

Tetragnathid spider with web ideally suited to catching stream invertebrates (site 30, Oro).

Dolomedes spiders are semi aquatic and can enter the water to catch stream life (site 25, Oro).

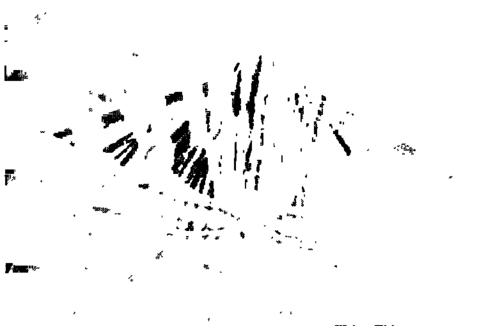


Ants are among many terrestrial invertebrates that are eaten by aquatic species (site 31, Oro).

Chlorocyphid damselflies have aquatic nymphs, but adults eat terrestrial invertebrates (site 27 Oro).

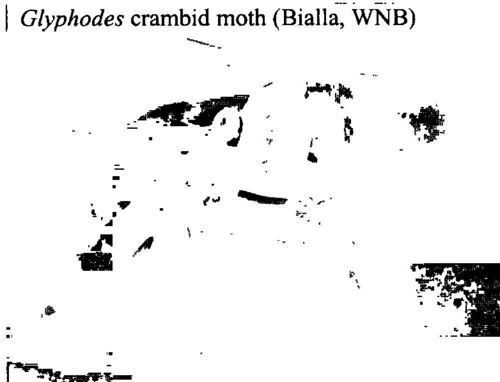
Figure 17. Examples of terrestrial and aquatic invertebrate interactions.

The biodiversity of terrestrial invertebrate communities is generally much greater than that of aquatic communities. A comparison of terrestrial invertebrate biodiversity values of oil palm versus native forest habitats would require a major monitoring programme, but snapshots of the terrestrial invertebrates seen in this study are shown in Figs 18 and 19.

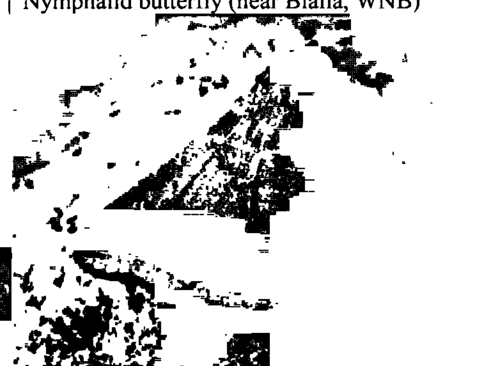


Glyphodes crambid moth (Bialla, WNB)

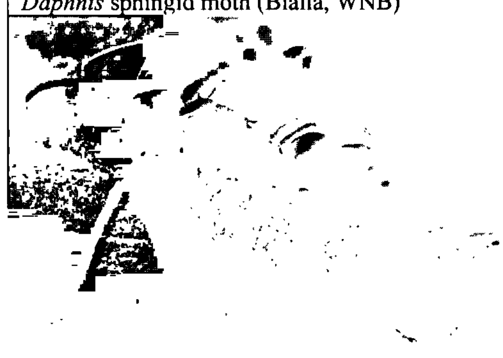
Nymphalid butterfly (near Bialla, WNB)



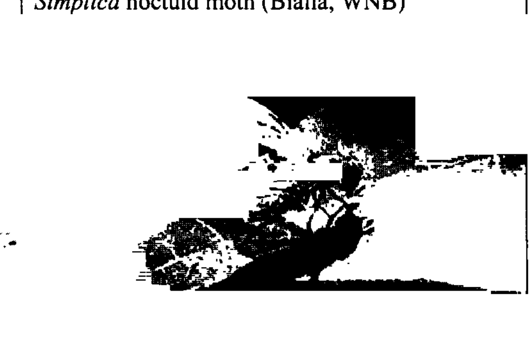
Daphnis sphingid moth (Bialla, WNB)



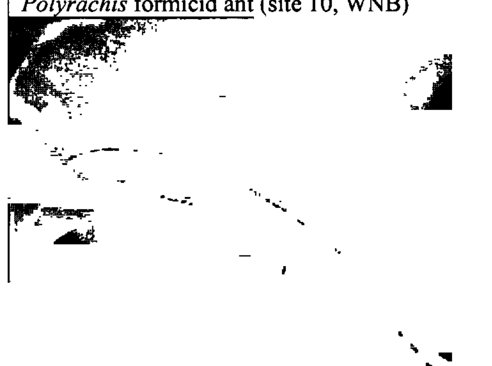
Simplica noctuid moth (Bialla, WNB)



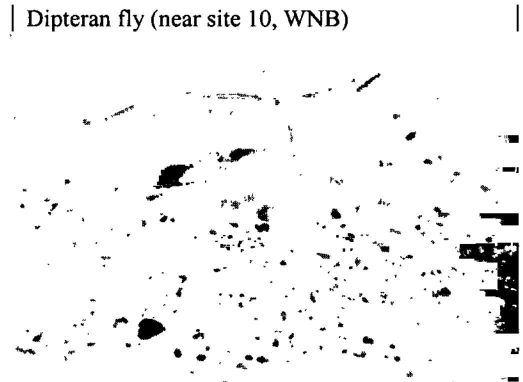
Polyrachis formicid ant (site 10, WNB)



Dipteran fly (near site 10, WNB)



Terrestrial bug (site 7, WNB)



Rhinoceros beetle, (Bialla, WNB)

Figure 18. Examples of terrestrial invertebrates observed in West New Britain oil palm areas.

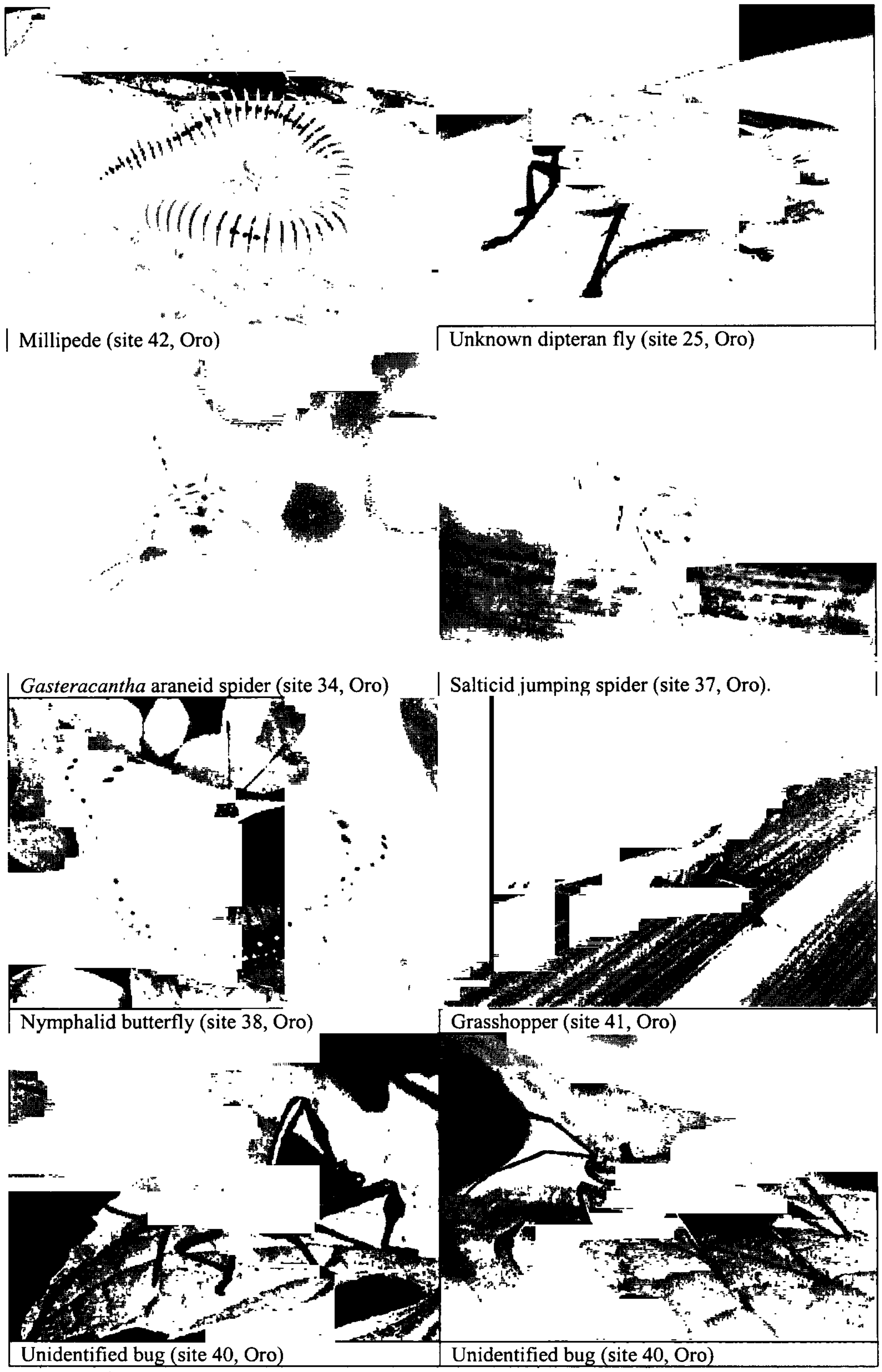


Figure 19. Examples of terrestrial invertebrates observed in Oro Province oil palm areas.

As a general observation, the terrestrial invertebrate faunas of the West New Britain and Oro Province oil palm areas appeared to be particularly rich among the Lepidoptera (butterflies and moths), Hemiptera (bugs), Coleoptera (beetles) and Araneae (spiders). Oil palm plantations often support an abundance of native under-storey vegetation, and these habitats are being utilised by many terrestrial invertebrates. A survey using a combination of light trapping, pit trapping and netting methods could assess the diversity of terrestrial invertebrate groups, and the proportions of native to exotic invertebrate species, in both oil palm and native forest areas.

3.7 Minimising the effects of smallholder oil palm operations

The oil palm and forest stream sites assessed during this study differed slightly in physical habitat conditions and biology, and some of these differences could be expected given that oil palm plantations are generally located on low gradient land and the remaining forest areas are often located on steeper topography. Some changes in stream biology are also inevitable following the change from native vegetation to oil palm plantations.

The main opportunities to minimise the effects of small holder oil palm activities on stream ecosystems are listed below:

Location of new oil palm areas:

- establishing new oil palm plantations in areas of existing poor quality vegetation (not primary or high biodiversity native forest),
- establishing new oil palm plantations in areas already serviced by roads (minimising the construction of new roads).

Road construction and maintenance:

- maintaining sealed roads, and preventing them from breaking down and eroding into streams,
- ensuring the types of vehicles using particular roads are suitable, and not too heavy given the road stability,
- ensuring the stable construction of bridges and culverts to avoid future slumping or collapse,
- ensuring new bridges and culverts do not create barriers to fish migration.

Protecting buffer zones:

- monitoring and enforcement to ensure smallholders comply with OPIC regulations of maintaining buffer zones, i.e. (a) 10m buffer widths for streams under 5m bed width, (b) 50m buffer width for streams over 5m bed width and for streams used by the community, or (c) 100m buffer width for coastal shorelines, lakes or significant swamps,
- where oil palms have been planted close to streams (before the buffer zone regulations), allowing native under-storey vegetation to establish along stream margins.

Safe use (or avoiding use) of chemicals:

- monitoring smallholder use of herbicides and any pesticides (whether these are applied by trained personnel and in accordance with appropriate guidelines),

- continuing to promote the manual clearance of weeds, rather than the use of herbicides, especially around drains, streams and wetlands,
- avoiding the storage of fertilisers in locations where fertilisers could be washed into watercourses, and
- promoting the use of pest biocontrol agents rather than pesticide chemicals.

4.0 Conclusions

Smallholder oil palm activities are known to affect stream ecosystems through pressures created by forest clearance, road construction, drainage works, the use of agricultural chemicals and water use by the growing human population.

Most of the West New Britain and Oro Provinces oil palm streams inspected during June–July 2006 supported an abundance of freshwater invertebrate life, including a typical range of taxa for tropical Asian soft-bottom streams (the PNG aquatic invertebrate fauna is largely of tropical Asian origin). Forest clearance and road construction are likely to have the most significant and rapid effects on stream ecosystems, but given time streams have the ability to flush sediment downstream, and invertebrate communities have the ability to re-colonise streams as the streambed stabilises and as bank-side vegetation regenerates.

Probably the most effective method of minimising the adverse effects of changes in land use on stream ecosystems is the protection of native vegetation along stream margins. The current OPIC riparian management guidelines (maintaining 10m, 50m or 100m buffer zones depending on stream type) should provide adequate protection for stream ecosystems. The on-going education of workers and residents in oil palm areas, regarding riparian protection, the safe disposal of domestic waste, and the appropriate handling of fertilisers and herbicides is also recommended, given that these people depend on streams for their own water supply.

Long term stream biological monitoring, using freshwater invertebrates as the primary indicators, should be undertaken to assess the effects of oil palm activities on stream ecosystems. This survey has produced baseline data that can be used for comparison with future biological monitoring results.

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