CHAPTER 4

Terrestrial Animals and Aquatic Invertebrates

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Introduction

Animals are important and conspicuous elements in-Pacific Island ecosystems. They are crucial to the flow of energy and nutrients within ecosystems and they strongly influence, and in some cases control, the species composition and population structure of communities. Determining which animal species are present in an area and what they do is crucial to understanding how ecosystems function and to appreciating the role and importance of biodiversity to human societies. This information is equally important to the management and preservation of biodiversity.

In this chapter we describe basic methods for conducting faunal surveys and reporting on the results, based loosely on DIWPA methodology (Toda and Kitching, 2002). We also emphasize the importance of using standardized methods for data collection and statistical analysis in order to facilitate the comparative interpretation and understanding of results, both within and between sites, and to provide a basis for comparison to other sites locally, regionally, and globally.

Our approach is by necessity broad; there is no single method that will work for all species or habitats. We focus on those methods that are most effective for surveying the kinds of animals that inhabit Pacific Islands. Our basic aim for each group is to produce lists of species and some indication of their relative abundance. Conducting surveys during different seasons will document seasonal patterns in abundance, reproductive periods and other life history features. Repeating surveys over time will provide important insights into population and other ecological trends within and between species. Combining and correlating survey data with biotic and abiotic data gathered by other investigators working along the same PABITRA transects will help to put survey results into a broad, integrated perspective.

Overview of the Pacific Island Fauna

Our knowledge of the distribution and diversity of the animals of the Pacific Islands is based mainly on brief reports from an enormous and widely scattered body of literature and from specimen collections in natural history museums. Pacific-wide treatments are available for relatively few taxonomic groups and for many invertebrate groups – especially insects – it is estimated that more than half the species remain unknown to science. By examining trends in the discovery and description of species at a world level for relatively well known groups, and determining the proportions of species from these groups found in the Pacific, we can construct crude estimates of the numbers of species in all groups likely to occur in the Pacific. This approach suggests that the Pacific Island region is home to about 918,000 species, approximately 15% of the world total (Table 4.1). In general, species richness is highest in New Guinea and declines eastward into the islands of Oceania. A high percentage of species are endemic to individual islands or archipelagos. Reference guides to the terrestrial animals are listed in the Bibliography.

Table 4.1 Estimated numbers of terrestrial species of Pacific animals by major taxonomic group. Numbers of arthropods were derived by extrapolating trends in well-known groups to all groups; mollusks are based on extrapolations from Cowie (1996). The number of other invertebrates is based on extrapolations from Hawai`i (Eldredge and Evenhuis 2002). The figures for vertebrates are based on species data bases and include estimates of the number of species yet to be described from the Papuan region.

Taxon	**Number of species**
Arthropods	900,000
Mollusks	6,000
Other invertebrates	9,000
Total Invertebrates	**915,000**
Fishes	350
Amphibians	600
Reptiles	500
Birds	1,035
Mammals	350
Total Vertebrates	**2,835**
Total	**917,835**

General Survey Principles

Faunal surveys involve systematic efforts to measure the composition and richness of animal communities from specific geographic regions. This fundamental approach originated with geographic exploration of the earth and the development of natural history museums beginning in the 17th century. Early efforts such as the U.S. Exploring Expedition in 1838-1842 in the Pacific generally involved only the scientific discovery and description of species. Modern surveys continue this process of species discovery and description, but also tend increasingly to focus on the population status and trends of specific animal groups (e.g., amphibians) in relation to environmental variables (e.g., global warming).

This information is increasingly important to understanding, managing, and preserving species and ecosystems. It also provides essential scientific understanding to guide natural resource management and planning.

It is useful to distinguish between two kinds of surveys: inventory and monitoring. An inventory survey mostly records only the presence or absence and a crude measure of relative abundance of a species in a given area, thereby providing only a snapshot in time. By contrast, monitoring involves repeated surveys at regular or irregular intervals to assess change over time in some factor such as population size or species richness.

Importance of Standard Methodology

In order to facilitate the comparative analysis of results, it is important that survey methodology be standardized in so far as possible across geographic regions and over time. This includes trying to conduct surveys at the same times of day and under similar weather conditions and using the same team members. Each survey method has advantages and disadvantages and results obtained by different methods may not be comparable. For example, bird studies that rely on only visual encounters to confirm the presence of a species would be difficult to compare with studies that establish presence by visual encounters and vocalizations. It is preferable to use a combination of methods in order to assure that the results are comprehensive and comparable with those of other studies across a broad spectrum of parameters.

The selection of survey methods depends on both the kinds of questions being asked and on the funding available. The basic question that needs to be asked prior to any survey is, “What do we hope to achieve”? Once this has been established, one needs to develop more precise questions, preferably phrased as testable hypotheses. It is also important to develop a detailed budget for the survey to ensure that adequate funding is available for its completion.

Faunal Inventories: Focus on Community Composition

Faunal inventories address the basic questions of which species occur in a geographic area (e.g., an island, biome, upland forest, agro-ecosystem or mangrove stand). It is important that all sites in the PABITRA network have as complete a faunal inventory as possible. However, even in this simple case, which generally produces only presence-absence and crude relative abundance data at a single point in time, careful thought must be given to sampling different areas and vegetation types with equal intensity, sampling all appropriate habitats within an area and using observational or trapping/capture techniques appropriate to the organisms being surveyed and to the terrain. In addition, it is important to keep in mind that data documenting the absence of a species in an area may be just as important to understanding overall distributional patterns and trends as is presence data. For example, predictive models that estimate the range of a species require both presence and absence data to give consistent results. However, it is generally easier to document the presence of a species in an area than it is to confirm its absence.

Monitoring Studies: Focus on Population Changes

Monitoring studies involve repeated surveys and are used to measure the distribution and abundance of species over time. This requires conducting an inventory to produce baseline data. Monitoring studies often address very specific questions involving predetermined standards (e.g., whether population size is above or below an accepted norm). Monitoring studies are also used to document the changing composition of a community and in this case will generally focus on a group of species or a taxonomic or ecological group (e.g., "seabirds"). There are many potential problems in measuring species abundance over time and in different geographic areas. For example, localized climatic differences may affect activity patterns and this may introduce an observational or trapping bias unless all surveys are conducted under similar climatic conditions. Similarly, the activity pattern of a species inhabiting an area where a predator is present may be different from that of the same species in an area where the predator is absent. It is essential to carefully consider these and other possible sources of error when designing such a study. It is also important to examine other studies that involve the same species or area in order to develop a sampling protocol that will produce comparable results.

Sampling Considerations

Spatial scale is a primary consideration in all surveys. The scale will depend on the kind of question being asked and the geographic range of the species or population being sampled. If the question involves a small, localized population, it may be possible to sample all individuals (e.g., all lizards on a small islet). For larger geographic areas it may be necessary to develop a randomized sampling method that uses statistical inference to predict the composition or abundance of the species or population throughout the region. In this case it will be necessary to select study plots or quadrats that are appropriate in size for the kind of organism and the geographic scale of the overall area being sampled. If, for example, one is documenting the richness of arthropods in the leaf litter within small isolated pockets of forest it may be appropriate to sample a few small plots within each forest. On the other hand if one is comparing bird species richness on different islands it may be necessary to sample large areas (e.g., 100 ha) within a range of different habitats over a considerable geographic area.

It is also important to pay close attention to the vegetation present in the general area to be sampled and to choose study plots within vegetation types appropriate to the types of questions being addressed (see Chapter 3 for details). This includes ensuring that plots are easily accessible, especially if a significant amount of equipment is being used. Having a laboratory available close by for storing and sorting samples is very useful and helps to enhance sorting efficiency and to reduce or eliminate the loss or damage of samples to insect pests, especially ants, or adverse climatic conditions.

Sampling Design

The use of statistics goes hand-in-hand with sampling considerations and depends on the specific questions being addressed (see Chapter 3 for basic details on selecting study plots and developing basic statistical measures of frequency and density that are relevant to faunal surveys). In general, statistics are used in two very broad ways: 1. To estimate some measurable component or feature of the animals or populations under study (e.g., population density); and 2. To test scientific hypotheses such as whether the density of a species is highest or lowest within a specific vegetation type or environmental zone.

It is normally impossible to accurately count all individuals of a given species within a modest to large sized geographic area, but by using sampling methods such as mark-recapture, one can use statistics to infer or estimate population size. Taking mark-recapture as an example, in the simplest case, we would capture and permanently mark a random sample of individuals, release them back into the population, allow them to remix with unmarked individuals and then capture another random sample. Assuming that there were no births or deaths and no immigration or emigration between sampling periods, the size of the population can be estimated as a simple proportion, where *r* is the number of individuals that were marked and released, N is the size of the population, and m is the number of marked individuals subsequently recaptured in a sample of n individuals:

$$r/N = m/n$$

Rearranging the terms and solving for N we get

$$\check{N} = rn/m$$

where $\check{N}$ is an estimate of N. This is often called a Petersen estimate or Lincoln Index.

Practical experience has demonstrated that for small samples (ten or fewer individuals) the formula

$$\check{N} = r(n+1)/(m+1)$$

gives a more accurate estimate. The Standard Error of the estimate for the general formula is:

$$SE_{\check{N}} = \sqrt{(r^2 (n+1)(n-m)/(m+1)^2 (m+2))}$$

The estimated population density would be calculated by dividing the population estimate by the size of the area sampled. In most instances, of course, there may be births or deaths between sampling periods and some immigration or emigration. This requires more complex formulae and sampling strategies that cannot be treated in this chapter. Well-written books on this subject are available (e.g., Begon, 1979; Magurran, 1988), as well as statistical textbooks and manuals that provide an overview of statistical techniques (e.g., Cochran, 1977; Snedecor and Cochran, 1989; Sokal and Rohlf, 1995).

It is particularly important when undertaking any study to develop a clear understanding of what needs to be sampled and how many samples need to be taken (= sample size). One must normally strike a compromise between the need, on the one hand, to reduce the sample variance and on the other hand to ensure that the study is completed within a reasonable cost and time. Chapter 3 provides details on using a running mean to determine sample size (see page 35). Other useful techniques are available for various sampling methodologies (Magurran, 1988; Fowler et al., 1998).

Standard Techniques

There is an enormous number of techniques to survey and monitor animal populations. Our emphasis in this chapter is on basic survey techniques suitable for producing species checklists and measures of population abundance. These methods can be repeated over time and across geographic areas to support related monitoring studies. In general, methods for surveying different animal groups are specific to those groups, although some techniques may be validly applied to a range of animal groups.

The PABITRA approach is based on DIWPA methodology in which detailed studies take place at a network of core sites that are already relatively well studied and have a good support infrastructure. Similar but less intensive studies take place at satellite sites (see Chapter 2 for details).

There is enormous variation in vegetation types along the PABITRA transects (Mueller-Dombois and Fosberg, 1998) and a variety of different survey and monitoring approaches are necessary. In general, we follow DIWPA in recommending that at core sites at least three randomly selected plots be established within a hectare of vegetation. Each plot should be surveyed using all appropriate methods. Each trapping or collecting effort should be run for at least three days at each plot and surveys should be repeated every three months in an on-going monitoring effort. The same basic methodology applies also to satellite sites but for logistical and financial reasons they cannot be surveyed as frequently or as intensely as the core sites. A full ecosystem inventory is required for all sites.

Sampling aquatic habitats may involve different methodologies than those involved in terrestrial sampling. It is important to recognize that a wide variety of aquatic habitats have resulted from the varying geological processes that formed each Pacific island and it is necessary to thoroughly examine all of these aquatic habitats to gain a full understanding of biodiversity of the study area. Aquatic habitats vary from obvious perennial streams and rivers to anchialine (brackish) ponds, coastal wetlands, taro wetlands, and rheocrenes (springs and seeps). Polhemus et al. (1992) provide a useful Pacific-wide aquatic habitat classification system that we use to help standardize our field surveys.

Invertebrates

Invertebrates include a wide range of animals that inhabit virtually every biome present in the Pacific region. In this treatment we emphasize two invertebrate groups: arthropods (insects and their kin) and mollusks. At the species level these two groups comprise an estimated 98% of the native terrestrial and freshwater animal biota of the Pacific region. Arthropods inhabit the soil, freshwater, and all types of vegetation in the Pacific region. In addition they generally have different life cycle stages (e.g., larva, pupa, and adult) and may occupy different habitats at different stages in their life histories. Many species are parasitoids at some stage in their life history.

Because ants are one of the most serious invasive animal species in the Pacific islands area, and are often a dominant group where they occur naturally, it is important to thoroughly assess ant populations at PABITRA sites. The sampling methods that we describe are appropriate for most ant species. Specialized methods may be required for some species. Full details are available in Agosti (2000).

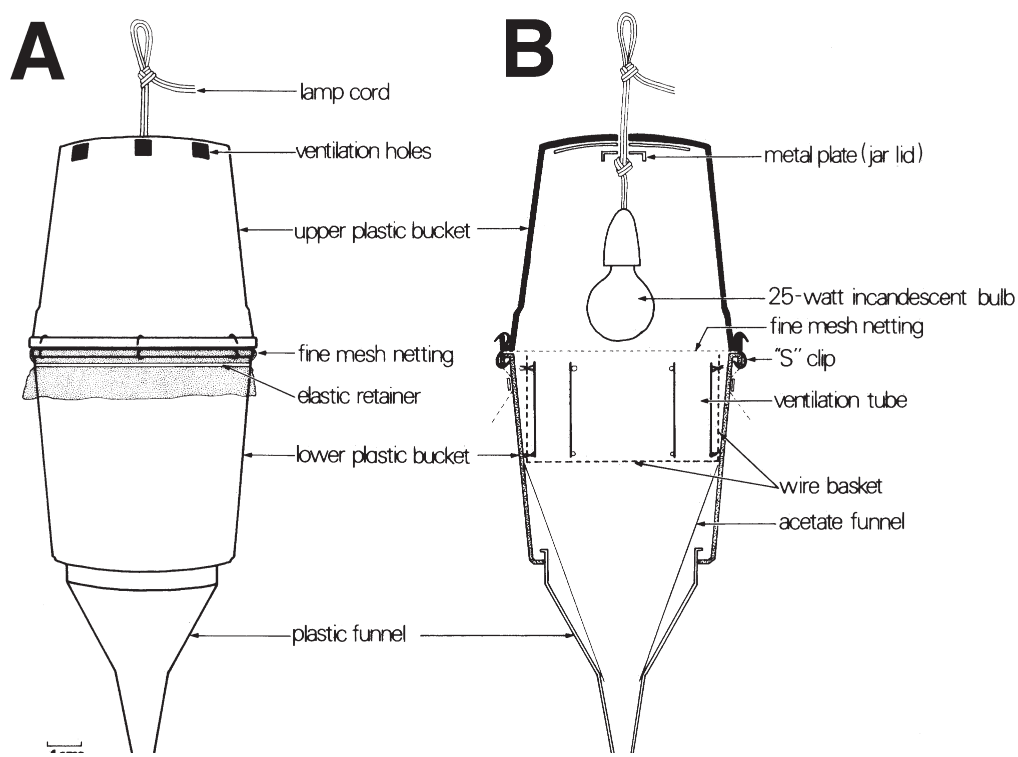

Figure 4.1. Berlese funnel for arthropods and other invertebrates from soil and leaf litter samples.

Figure 4.2. Neal Evenhuis using a sweep net in Fiji (photo: Dan Polhemus)

Mollusks are found in a wide variety of terrestrial and aquatic habitats, thus a wide variety of techniques are required to effectively sample these taxa. Land snails are mostly found on live vegetation or in the leaf litter; aquatic mollusks occur in all aquatic habitats. Invasive snail species are of particular importance, and the extent of their distribution on each Pacific island sampled should be carefully noted. The following sections briefly describe sampling techniques for terrestrial and aquatic arthopods and molluscs.

Funnel Extractors—Arthropods that inhabit soil and leaf litter can be sampled using various extraction techniques. One of the simplest techniques uses Berlese or Tullgren funnels (Figure 4.1). A sample of freshly collected leaf litter or soil is placed in a funnel set over a container of liquid preservative (e.g., 70% ethanol). As the sample dries from the top, the insects, mites, and other arthropods migrate downwards and eventually drop into the preservative. The Tullgren technique employs an artificial heat source (such as an incandescent light) to dry the sample; the Berlese technique is identical except it relies on natural evaporation to dry the sample. Once samples are extracted the dry litter should be weighed. The results can be standardized per unit dry mass of litter.

Flotation Methods—There are a number of techniques that rely on chemical extraction and flotation to obtain arthropods from soil samples. One reasonably simple technique relies on the fact that the arthropod cuticle can be wetted by various hydrocarbon solvents such as gasoline. A soil or leaf litter sample is placed in a mixture of gasoline and water and shaken. The contents are then allowed to settle. The arthropods will tend to be found in the gasoline layer (which floats above the water) while soil, leaves, etc. will tend to be found in the water layer. However, this technique is dangerous because of the toxicity of the chemicals and is difficult to standardize.

Nets—Arthropods, mainly insects, that fly or perch on low vegetation can be sampled by sweep-netting (sweeping an insect net back and forth a standardized number of times directly around and over vegetation in a particular habitat) (Figure 4.2). In many cases the time of year or the time of day that the sampling takes place is critical and needs to be standardized. Aquatic insect sampling using aerial sweep nets is one of the most effective methods of assessing arthropod biodiversity in aquatic habitats. Because most stream insects in the Pacific island region have evolved from ancestors that inhabited marine splash zone areas (Howarth and Polhemus, 1991) aerial sweep–netting of adult aquatic insects should focus on suitable habitats that include splash zones around riffles, cascades, and waterfall areas. Other areas that should be swept include wet rock faces associated with springs and seeps and wetland areas near and along stream corridors. Telescopic sweep nets are especially useful in assessing high cascade and waterfall areas and boulders in wide streams. The major advantage of aerial sweep-netting is that it is very effective; however, the large numbers of insects and the diversity of species often collected can be daunting to both curate and identify.

Benthic Sampling—Benthic sampling can be accomplished in a number of ways: either through enclosed quantitative methods such as the square Surber sampler or the round Hess sampler, or more simply by having one observer kick the substrate vigorously while holding a fine-meshed net downstream of the disturbed area. Kick sampling is usually adequate for biodiversity surveys, as the first "kick" has been found (in continental regions) to disturb 60% of the fauna yielded by 10 additional kicks (Southwood and Henderson, 2000). Kick sampling also requires a minimum of equipment compared to either Surber or Hess samplers, and this is an important consideration when accessing remote stream areas. Hand collection, using forceps, of aquatic biota from the stream substrate is also highly recommended, and, when combined with kick sampling is an effective method for the collection of larval stages of aquatic arthropods. Rocks found in riffles can be held over a large plastic bowl, and by using either a soft-bristled toothbrush or fine-point forceps, molluscs and immature arthropods can be extracted from the algae or moss covering the rocks. Some aquatic mollusks such as Neritidae are nocturnal and shelter deep in the stream bottom during the day, so it is important to dig deep into the stream substrate when sampling during daylight hours.

In temperate continental regions most adult aquatic insects are short-lived, while immatures have much longer life cycles (Merritt and Cummins, 1997). The immatures are generally well known and are readily sampled in run and riffle habitats where they occur in the greatest numbers. In tropical Pacific insular regions, such as Hawai‘i, the adults of most aquatic insect species are found in streams throughout the year (Englund and Polhemus, 2001), as are the immatures, which typically occur in greatest numbers in waterfall and highly turbulent cascade areas. Because the immature stages of most Pacific island aquatic insect species are unknown, it is important to sample the adults; heavy reliance on benthic sampling of immatures, where only family or generic identifications are possible, will seriously underestimate community diversity (Merritt and Cummings, 1997).

Figure 4.3. Hand aspiration of insects (photo: R. A. Englund).

Aspirators and Vacuum Devices—A laborious but potentially accurate technique for surveying insects on plants is to visually examine the plant (or a standard number of leaves or branches) and collect all insects by using an aspirator or suction bottle (Figure 4.3). Vegetation can be mass-sampled using a vacuum device powered by a motor (Figure 4.4). This technique can be standardized by examining a specific number of plants or vacuuming for a set length of time.

Direct aspiration is also an important collection method for aquatic insects because many species will not be captured by sweep-netting and benthic sampling (e.g., some diptera such as *Telmatogeton* spp. in Hawaii and aquatic Saldidae found in Hawaii and French Polynesia). This unconventional aquatic sampling method requires visually tracking insects as they move around the stream rocks and collecting them directly with an aspirator. It is best to have an aspirator nozzle of approximately 120 mm in length, and at least 7 mm in diameter. Shorter and thinner nozzles are less effective. For direct aspiration to be effective, experience and a good general knowledge of the aquatic insect biota are required, as it is a difficult and time-consuming capture method.

Canopy Fogging—This is the most effective method for collecting canopy arthropods. A portable fogging machine is used to envelope a tree canopy with a cloud of quick knock-down insecticide such as pyrethrum (Figure 4.5). Arthropods are killed on contact with the cloud and fall into collecting trays suspended beneath the tree (Figure 4.6). Trees should be fogged in the morning at first light when wind disturbance is minimal. This technique is suitable for fogging individual trees and can also be used to sample randomly determined plots within a forest. The DIWPA manual (Toda and Kitching, 2002) recommends selecting plots that include a 10 x 10 m segment of the mixed

Figure 4.4. Gas aspirator device for mass sampling insects on vegetation (Photo: D. Preston).

species high canopy. The trays should be left in place for at least two hours, optimally four hours. Canopy fogging can result in thousands of specimens and these can be laborious to sort so investigators should plan accordingly.

Selective fogging of aquatic habitats with pyrethrins can also be an effective method of collecting aquatic insects, as immatures and adults may be so deeply embedded in aquatic substrates (i.e., mosses and algae) that they otherwise would not be collected. Especially convenient and effective are small handheld household pyrethrin insect foggers manufactured by Ortho® and others. Only a small area needs to be fogged, for example a 30 x 30 cm area of mossy rocks in, or very near, the splash-zone of a waterfall or seep. It may take several minutes for the fog to take effect after which the insects can be aspirated or collected with forceps. On many small Pacific islands it is often difficult to find a stream that is not eventually diverted for drinking water, thus fogging should be done in a judicious manner and not used upstream of drinking water in-

Figure 4.5. Fogging a forest canopy (Photo: A. Allison).

Figure 4.6. Simple, inexpensive collecting trays suspended under the forest canopy for collecting fogging samples (Photo: A. Allison).

Figure 4.7. Light trapping (Photo: R. A. Englund).

takes. Handheld foggers can be carried in a backpack when sampling remote areas, and can also be used for terrestrial sampling in areas that are inaccessible with large portable fogging machines.

Light Traps—This technique uses a powerful light such as a mercury-vapor (MV) or ultraviolet (UV) lamp to attract flying insects at night. The insects settle on a cloth sheet near the light and are hand collected (Figure 4.7), or they hit invisible clear plastic baffles around the light source and drop through a collecting funnel to a container where they are killed by a lethal chemical or liquid preservative. This latter kind of trap can be hoisted into the canopy and is arguably the most effective method for standardized sampling. The efficacy of light traps is influenced by weather conditions, phases of the moon, and other environmental variables, so developing a standardized sampling technique can be problematic. It is important to avoid periods of full moon and ensure there are no competing light sources. It is useful to install light traps where possible in the tree canopy and also near ground level. Different species fly at different times of night so it is important to have the traps in operation from dusk until dawn. Traps should be operated for at least three days per site. The number of insects collected can be enormous and it may be necessary to frequently change the collecting container. Samples tend to be dominated by Lepidoptera and it is necessary to spread and pin butterflies and moths shortly after they are collected in order to obtain good specimens for identification. Beetles and most other insect groups can be preserved in alcohol.

When conducted alongside wetland or stream-side habitats, light trapping is an effective method of capture for aquatic insects. Because many adults in the fly families Chironomidae and Tipulidae are primarily nocturnal, night sampling is often the only way to collect these taxa. Light trapping, alone or in conjunction with daytime sweep-netting and aspiration, will ensure that the greatest number of adult aquatic insect species is collected during a biodiversity assessment.

Windowpane Traps—As the name implies these traps use a clear pane of glass or plastic suspended above a tray of preservative (e.g., ethanol or a soap solution) (Figure 4.8). A variation on this involves two transparent vanes that intersect at 90 degrees (Figure 4.9). In both cases flying insects are stunned when they hit the “windowpane” and drop into the preservative. These traps are relatively inexpensive and can be left in place for extended periods but they should be checked daily and the samples removed and preserved. Where possible, traps can be placed in the tree

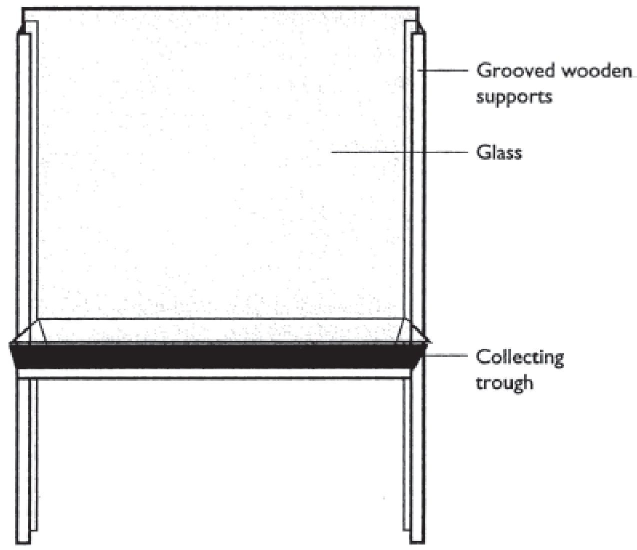

Figure 4.8. Traditional windowpane trap.

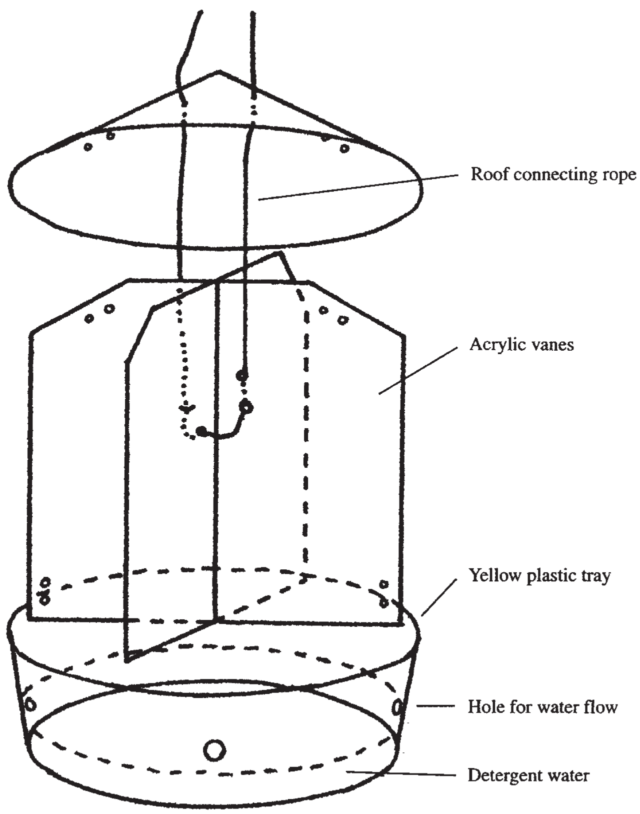

Figure 4.9. Hanging windowpane trap (after Toda and Kitching 2002).

canopy and at ground level to comprehensively sample forest habitat.

Yellow Pan Traps—Simple in design and operation, yellow pan traps are an invaluable and easy addition to a sampling protocol. They involve a bright yellow pan or shallow container filled with water and a surfactant (diluted ordinary dish soap works well) to break the surface tension. Many species of flying insects are attracted to the yellow color and become trapped in the water and drown. We prefer round plastic bowls that are about 10 cm in diameter and can be filled to a depth of 2-3 cm. These are lightweight, small and can easily be transported to remote areas. Although other colors of bowls or pans can be used and may collect insects that are attracted to specific colors such as white or blue, yellow is the most effective at collecting a high number of different species.

Traps are usually placed on the ground, but can also be placed in tree limbs or near riffle, cascade, stream, or shoreline habitats. For aquatic sampling it is important that the trap be placed near or within the splash-zone of the riffle, cascade, or waterfall area. If necessary, a few small rocks can be placed around the pans to keep traps from floating away.

Insects will decompose rapidly, so traps should be checked and samples removed as often as practicable. Traps can be left overnight but it is best to check them every few hours and to preserve the samples in ethanol.

Malaise Traps—Malaise traps are square, tentlike structures made of nylon mesh and are supported by either a central pole or guy-ropes suspended between trees (Figure 4.10). The tent roof slopes upwards to a receptacle filled with either a chemical such as potassium cyanide embedded in plaster of Paris, or a liquid such as ethanol. The principal of the Malaise trap is that arthropods encountering the cloth netting climb or fly upward and are collected in the receptacle at the top. Malaise traps are especially effective in trapping rare and unusual arthropods. Where possible, traps should be deployed in the canopy and also at ground level. Malaise traps at ground level can be used in combination with yellow pan traps to more completely sample the full spectrum of flying insects. Species

Figure 4.10. Malaise trap (Photo: R. A. Englund).

that drop or fall downwards after hitting the net panels are captured in the pan traps.

Malaise traps are also an effective adult aquatic insect capture method, and in small streams are placed over the stream channel to capture newly emerging adult insects. Traps can be left in place for a variable amount of time, but at a minimum should be kept in place for 1-2 days.

Pitfall Traps—These come in a wide variety of sizes and are used to sample ground-dwelling arthropods. Most designs involve a vertical-sided container that is sunk into the ground so that the top is flush with the surface of the soil or leaf litter. Arthropods fall into the traps and are unable to climb out. Some investigators prefer to put a preservative such as ethylene glycol in the bottom of the container to ensure that all arthropods falling into the trap are collected. However, there is some evidence that the odor from preservatives may repel some species and may be lethal if consumed by vertebrates. It is difficult to ensure that the top of the trap remains flush with the soil surface, especially in areas with high rainfall, and standardizing the use of pitfall traps can be difficult.

Bait Traps—Various kinds of bait are useful for attracting insects to collecting traps. For example, peanut butter works particularly well for some species of ants. Small wooden ice cream spoons or chopsticks dipped in peanut butter, and placed at regular intervals within a transect provide valuable information on ant abundance and distribution. Other baits that can be used to collect ants include honey or canned fish-based cat food, but peanut butter seems to be the easiest and most effective ant bait (Figure 4.11).

Bait stations are particularly important when sampling flies of the genus *Drosophila*. Baits can include rotting mushrooms, bananas or meat soaked in water. The bait is smeared on small sponges or other absorbent material and placed on tree trunks or other substrates where attracted insects can be directly aspirated from the baits. The bait can also be used to attract insects into pitfall and funnel traps. Narrow-necked plastic bottles, such as water bottles, can also be used as bait traps. For some insect groups, such a tephritid flies, chemical attractants such as methyleugenol or cuelure can be used to attract the insects into funnel traps. Such chemicals are potentially dangerous and should be used with great care.

Visual Collecting Methods for Mollusks—Mollusks are found in leaf litter, in freshwater, and on plants. The best ways to sample them are to use visual observation and sieving techniques. These include searching all appropriate habitats (e.g., on plants, under logs) and collecting samples of leaf litter or soil and carefully searching this under a dissecting microscope (many species of land snails have shells that are less than 1 mm in diameter). Because of the small size of most terrestrial land snails, sieving generally is done at a later time and not in the field. This entails putting the sample into four-liter size plastic bags in the field, and packing the samples back to an area where the litter can be laid out and dried. After drying, the leaf litter or soil is placed into a fine-mesh sieve and sorted with tweezers. Using fine-meshed sieves is important to ensure collection of smaller terrestrial mollusks. Because many Pacific island areas are quite wet, it is important that the litter or soil is allowed to dry before sieving begins. These techniques can be standardized in various ways – such as timing the duration of the search effort, searching a certain mass of leaf litter, etc.

General Vertebrates Considerations

Although vertebrates comprise only about 2% of the world's animal species, they tend to be the largest and most conspicuous animals on Pacific islands. They are by far the best-known animal group and have a strong public following. This often makes them species of special concern to resource management agencies. For these and many other related reasons vertebrates are an important component of Pacific island biodiversity surveys.

Figure 4.11. Ant bait traps (Photo: D. J. Preston).

Vertebrate data are particularly useful for quickly determining patterns and trends in species richness within and between sites, along environmental gradients, and in association with different kinds of vegetation. In order to address species specific questions (e.g. conservation status), it may also be important to determine population size or abundance for species at the different sites. This is much more challenging and often requires special effort and methods for each species.

Vertebrates of many parts of the Pacific region are incompletely known, particularly amphibians and reptiles and to a lesser extent mammals and birds, so it is often important to collect and preserve specimens to document and scientifically name new species.

Amphibians and Reptiles

These range in size from small frogs to large crocodiles and snakes that may exceed 4 m in total length. Most species are ground-dwelling but some, especially turtles and crocodiles, are mostly aquatic and others are highly arboreal. Sampling such a diverse assemblage is difficult.

Hand Collecting—The best way to compile a complete species inventory is to visually examine appropriate habitats – including leaf litter and soil, under logs and other surface debris, in shrubs and trees including under exfoliating bark and within the forest canopy during the day and at night and during different times of the year. Most species of amphibians and reptiles can be caught by hand. Species of lizards that are particularly wary or fast-moving can be stunned with large rubber bands. Poisonous snakes should be handled only by experienced personnel using snakes sticks (long handled poles with steel hooks at the end) or grabsticks (long-handled tongs). Visual census and other active searching techniques can be standardized – to some extent – by ensuring that equal effort (e.g., search time) is expended in all areas.

Pitfall Traps—These can vary in size depending on the species being sampled, but generally involve a 20 liter round plastic or metal container embedded in the ground. These containers, which must have smooth vertical sides and can be purchased from hardware stores and paint supply companies, generally have a mouth that is about 30 cm wide. To avoid filling with rainwater, the containers can be covered with lids affixed 2-3 cm above the tops so that there is a space for the animal to crawl through. Alternatively, a wooden or plastic cover suspended above the ground will also work well. Pitfall traps are generally effective only for relatively small amphibians and reptiles; larger species can generally get out of the traps. Some investigators prefer an x-array in which traps are placed at the ends of two fences that cross in the middle; others use three fences radiating from a trap at 120-degree angles from one another and with another trap at the other end of each fence. Others simply place the pitfall traps flush at either end of a single drift fence and at set distances along the entire length.

Glue Traps—These are small cardboard squares covered with a sticky adhesive such as Tanglefoot™ and available commercially for trapping mice. Glue traps can be deployed individually on the forest floor where small lizards and snakes are active or arrayed into a network with drift fences. Reptiles are easily removed alive from the traps using cooking oil as a solvent. Glue traps tend to build up quickly with debris and must therefore be replaced frequently to remain effective. Ants will often quickly attack lizards or snakes captured in the traps, particularly in cases where part of the animal is accessible off the edge of the trap. Traps should therefore be checked as frequently as possible.

Drift Fences—These are 30-50 cm high fences, constructed from plastic sheeting or similar material, that channel animals towards pitfall, funnel, or glue traps. Their length can vary, depending on the terrain, but they usually don't need to be more than about 10 m long, although longer fences result in better samples. The arrangement of the fences can vary widely. It can be helpful to have several fences radiating outwards from a trap.

Standardized arrays of drift fences and pitfall traps can be replicated across different sites although differences in terrain can make standardization difficult. Replicated arrays of drift fences are useful for monitoring studies in which traps are installed semi-permanently at a given site and deployed on a regular basis. Traps should be covered or removed when not in use.

Frogs or reptiles encountering drift fences tend to move along them and to drop into the pitfall trap at the end. Most small species of ground dwelling lizards or frogs are unable to climb out of the trap and can be collected alive. Traps should therefore be examined frequently; this will also help to establish the activity times of the various species. Some investigators prefer to put a shallow plastic funnel (e.g., a large margarine tub with the bottom cut out) at the mouth of the pitfall trap. This helps to ensure that animals that can crawl up the side of the trap don't escape.

Quadrat Sampling—Other methods for surveying amphibians and reptiles include the use of quadrat, patch, and transect censuses, and for frogs, the use of audio strip censuses. The quadrat method involves an intense search for all individuals within a small square of habitat at randomly selected sites. Each quadrat comprises an independent sample and a large array of quadrats can provide data for monitoring population changes, comparing species richness in different geographic areas, determining species composition and richness in different habitats and a wealth of other ecological information. This same basic approach can be used to sample different microhabits or patches such as under logs, within tree buttresses, within the leaf axils of palms, etc.

Transect Sampling—The transect census is similar to the use of quadrats except that a linear transect of a standard distance is determined randomly and quadrats of standard size are searched on either side of the transect. There are many variations on this theme – every quadrat on either side of the transect is searched or alternate quadrats are searched, etc. Each transect constitutes an independent sample and the results provide information on such features as species richness and the abundance of species across environmental gradients.

Audio Strip-Censuses—The males of nearly all frogs that occur in the Pacific region are vocal. Many species, particularly in the family Microhylidae, tend to call and breed throughout the year while other species, particularly frogs in the family Hylidae, may have concentrated breeding seasons when most calling activity takes place. Depending on the circumstances and the species being studied, it may be possible to establish transects and conduct audio censuses to determine the distribution and richness of species along environmental gradients.

Microhabitat Observations—In all cases it is useful to record details about the microhabitat where an animal is captured and for arboreal species it is often important to record height above the ground and the diameter of the perch.

Automated Data Loggers—A number of instruments have been developed to automatically record data from the field. These include tape recorders and solid state devices for recording vocalizations. These devices have been used with considerable success to record frog choruses at different times during the night and day. Such an approach requires prior knowledge of the calls of the component species. It is also necessary to carefully compare the recordings with field observations made at the same time in order to reliably interpret the results.

Birds

Most species of birds are active during the day, are relatively easy to observe, and have a large public and scientific following, making them the best known group of vertebrates in the Pacific region. However, because most birds can fly, it is sometimes difficult to establish which species are actually resident in an area. Some species, such as the golden plover (*Pluvialis dominica*), migrate large distances to breed and are present in the tropical Pacific region for only part of the year. Many species of sea birds forage over a wide area but congregate seasonally to breed in very limited parts of their range. Some birds, for example, several species of cuckoos, are represented by migratory forms that are present seasonally and resident forms that may be present all year. In addition some birds are native to some parts of the Pacific but have been introduced by humans to other parts of the region.

Birds can be separated into four dispersal groups. Most that reproduce in an area are regarded as breeding birds. Those that regularly appear seasonally but don't breed in the area are regarded as migrants. Species that occasionally reach an area are known as vagrants. Birds that have been deliberately or accidentally brought to an area by humans and have established breeding populations are known as introduced species. Much of this information for birds of the Pacific has been summarized in a number of excellent field guides that together cover the entire tropical Pacific island region.

Inventory Methods—All that is usually required to survey birds is a good pair of binoculars and knowledge of the species likely to be found in the area. However, some species are extremely secretive and others are nocturnal making it necessary to carefully examine all appropriate habitats during the day and at night. In addition, to record migratory species it is necessary to survey an area at different times of the year. It is often helpful to use mist nets – nearly invisible nets constructed from very fine thread and suspended on poles to intersect and catch flying birds. Mist nets are particularly useful for revealing the presence of secretive and skulking species. In addition, by becoming familiar with bird songs and bird calls one can record the presence of a species without actually seeing it. This makes it possible for an experienced person to rapidly survey an area and compile an accurate inventory.

Line Transects—Although it is relatively easy to inventory an area for birds, it is somewhat more problematic to determine the relative abundance of the different species. Many observers simply classify a species into five abundance classes such as vagrant, rare, uncommon, common, and abundant. For more rigorous results it may be necessary to make observations along a line transect. In order to preserve the independence of the data, transects should be determined randomly and in sufficient density to ensure that population counts are accurate. Specific census protocols depend on the species being studied but in general all observations should be conducted in the first few hours of the morning when birds are most active. It is often useful to work in pairs so that observations can be compared and to ensure the safety of the observers while in the field.

In one variation of the line transect approach, the observer records distance, perpendicular to the transect line, of all birds seen and heard while slowly walking along the transect. From these data one can construct a model of detectability and from that calculate population density. A different approach is to establish stations or points along the transect and determine distance and direction of all birds seen and heard for a certain period of time from each station (eight minutes was adopted as the standard for the Hawaii Forest Bird Survey [Scott and Pratt, 1986]). These data can then be assembled into a model to determine density. In both cases it is necessary, particularly in environmentally heterogeneous terrain, to also record details about the vegetation so that density measurements can be correlated with different vegetation types and assembled into population estimates at the landscape level. The overall accuracy of these approaches depends on a large array of factors including the ability of the observers to accurately record all birds along the transects or observing stations, the accuracy of the distance estimations, and assumptions that birds are not fleeing from or approaching the observers and are counted only once. In practice some of these factors can be taken into account during data analysis to produce more accurate population estimates.

Mark and Release—It is also possible to census birds using mark and release techniques. Birds can be caught with mist nets or by other means, including hand capture for nesting seabirds, and marked with permanent metal leg bands. This method is laborious but is one of the best approaches for monitoring the population density, life history, and demography of a species.

Nest Counts—To monitor seabirds and other colonial nesting species it is often possible to count the number of nesting pairs within representative designated areas and, using the proportion of these areas to the overall area occupied by the breeding colony, to obtain an estimate of the size of the breeding colony. These estimates can be compared between years to identify general demographic trends.

Mammals Other than Bats

Pacific mammals are one of the most difficult groups to study because they are mostly active at night and have very secretive habits. They are therefore difficult to observe and census and their presence can generally be detected only when they are captured in traps or nets, although some species can be detected by their scats or vocalizations or by observing at night with night-vision devices or powerful spotlights. This latter method is highly intrusive and is likely to interrupt normal behavior.

Live Trapping—The methods for studying non-flying Pacific mammals are similar to those for amphibians and reptiles and rely heavily on various kinds of trapping and detection methods suitable for documenting the presence of all species in an area to produce an inventory. More detailed population data can be obtained by organizing the study along randomly determined line transects. Although it is possible to use pitfall traps (see Amphibians and Reptiles, above) for trapping some species of small mammals, it is preferable to use live traps. Folding aluminum box traps generally known as Sherman (U.S.) or Elliott (Australia) traps are available in various sizes for small mice to large rodents. For larger mammals suitably sized box traps constructed from wire mesh are available. In all cases the animal is enticed inside with bait (peanut butter and oatmeal are a popular combination) and is captured when it hits a treadle which closes a spring-loaded door.

Each type of trap has advantages and disadvantages. Some mammals are reluctant to enter box traps. Many carnivores, particularly the small species such as dasyurid marsupials, require live bait (such as large insects). In addition, many species are largely, if not exclusively, arboreal and traps have to be set in the trees. For these reasons surveys of small mammals also include the use of snap traps. Although lethal, they will often trap species that will not otherwise enter live traps. They also have the advantage that they can easily be affixed with nails to tree trunks and branches.

Automatic Recording Devices—There are also automatic devices that photographically record the presence of an individual when it interrupts an infrared beam or hits a tripwire. This can yield valuable information on the presence and activity patterns of secretive species. Interpretation of the photographs requires a good understanding of the species occurring in the area.

Bats

Mist Nets and Harp Traps—Bats present a special challenge because they are exclusively volant and nocturnal. The small species can be captured using mist nets as with birds. These nets can be set in open spaces frequented by bats and can even be placed, using pulley systems, in the forest canopy. Flying bats can also be captured in specialized traps generally known as harp traps. This latter trap consists of a rectangular metal- or wood-framed vertical array of closely spaced wire or nylon fishing line with a plastic trough attached to the bottom. The vertical lines are too small for the bat to detect by sight or with its sonar; it is intercepted when it attempts to fly through the trap and drops down into the plastic trough from which it is unable to climb out. Harp traps can be raised into the tree canopy and are therefore useful for trapping high-flying bat species. However, because the trap samples only a very small portion of the existing space, each trap generally yields a low number of captures.

The fruit bats, which often have wingspans of a meter or more, can be captured in the same way as the insectivorous bats. However, because of their size and strength they can quickly destroy mist nets. Some investigators have collected fruit bats with large harp traps. Because most species of Pacific fruit bats nest communally in canopy trees or caves it is generally easiest to census them at these sites. Many of the insectivorous bats also roost in caves and can be censused there during the day.

Special Handling Precautions—Many species of mammals, particularly bats, can carry diseases dangerous to humans and should be handled with care. Thick gloves are recommended for handling specimens and removing them from mist nets or harp traps.

Data Acquisition and Processing

Importance of Voucher Specimens

Many species are poorly known or difficult to identify in the field. It is therefore highly desirable to collect specimen vouchers and deposit these in museums to permanently document the data. This provides an opportunity for taxonomic experts to confirm the identifications and allows later investigators to verify or reassess the findings and provides useful material for follow-up studies (e.g., analysis of stomach contents) or subsequent taxonomic reassessments. Voucher specimens are particularly important to document new range extensions and are crucial for the description of new species. There are a number of useful manuals available for preparing and preserving voucher specimens and recording appropriate data. The accompanying data are as important as the specimen and should include details on when and where the specimen was collected, including, if possible, exact latitude, longitude and elevation, together with the name of the collector, important body measurements and habitat and microhabitat details.

Notes and Recording Forms

All survey data and all noteworthy ecological observations should be recorded in permanent, waterproof field notebooks in pencil or archival and waterproof inks. This should include all pertinent information such as location, time, weather conditions and all observations.

It is useful to prepare pre-printed forms for recording the data. This helps to ensure consistency in the collection of the data and facilitates efficient transcription into computer databases and spreadsheets for analysis. The development of the form should be based on the goals of the survey and should include ample space for all pertinent information. After designing a form enter some trial data to make sure that the form works as intended. Every form should have a place for the date and locality. It may be necessary to enter species information in coded form to save space in which case a coding key should accompany the form. Appendix 1 includes sample forms.

Methods of Analysis

The methods used for analysis and interpretation of survey and monitoring data are as varied as the kinds of organisms and types of studies undertaken. Data obtained from randomly determined quadrats or from quadrats sampled along transects can be analyzed using powerful multivariate statistics. See Chapter 3 for details on methods of analysis for the similar Relevé Method for plants. A specific review of analysis methodology is beyond the scope of this chapter; good summaries can be found in Heyer et al. (1994), Wilson et al. (1996), Bibby (2000), and Southwood and Henderson (2000). These and other manuals also provide useful details on the use of statistics to interpret survey results.

Data Presentation

Scientific Publications

All important findings such as new range extensions should be published in scientific journals or books. These publications mostly have a peer review system to assure quality and are professionally produced to a high editorial standard. Space is often very limited and only the most noteworthy findings are generally accepted for publication. However, these publications generally have a wide circulation and are an effective means of bringing important findings to the attention of the broader scientific community.

Web Publication

The Web provides for broad access to virtually unlimited amounts of data and is increasingly the preferred outlet for the dissemination of survey information. However, in most cases Web-accessible data and findings have not been peer reviewed and are likely to vary widely in quality. In many cases this potential deficiency can be overcome by depositing voucher specimens to document important findings as discussed earlier.

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Appendix 1. Example data collection forms.

Soil and Leaf Litter Extractions

Collector ______________________________

Litter collection information

Date ____________

Time ____________

Location ______________________________

Elevation ____________

GPS location lat ____________ long ____________

Habitat type ______________________________

Litter condition ______________________________
(e.g., wet due to recent rain)

Funnel Number	Date extraction		litter dry mass (g)	sample vial number	sample complete (y/n)
	started	complete			
1					
2					
3					
4					
5					
6					

Comments ______________________________

Light Trapping

Collector ______________________________

Light trap details

Trap number ____________

Date started ____________ time ____________

Date ended ____________ time ____________

Location

Site ______________________________

Elevation ____________

GPS location lat ____________ long ____________

Trap position ______________________________

Habitat type ______________________________

Weather conditions ______________________________

Phase of moon ________________

General observations ______________________________

____

____

____

____

Amphibians and Reptiles

Collector ______________________________

Type of survey ______________________________

Date ____________

Time start ____________
Time end ____________

Location ______________________________

Air temperature ____________ (^{o}C)

Windspeed ____________ (Beaufort scale)

Precipitation ____________ (during survey)

Weather prior to survey ______________________________

Habitat type ______________________________

Species	Sex	Vocalization index	Microhabitat	Activity	Substrate	Time	Comments

Comments ______________________________
____
____