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Report

A Comparison of Terrestrial Arthropod Sampling Methods

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Abstract: Terrestrial arthropods are extremely important ecosystem components. The choice of best approaches to collect the wide range of terrestrial arthropods has been a topic of long-lasting debates. This article provides a brief overview of common sampling methods for terrestrial arthropod assemblages. We divide sampling methods into three main categories: passive sampling methods without any "activity density" bias, passive sampling methods with an "activity density" bias, and active sampling methods with inherent "activity density" and often further species-dependent biases, discussing their individual advantages and shortcomings as basis for biodiversity studies and pest control management. The selection of the optimal sampling methods depends strongly on the purpose of individual studies and the ecology and behavior of the arthropod groups targeted. A combination of different suitable methods is highly recommended in many cases.

Key words: terrestrial arthropods; sampling methods; comparison; activity density

1 Introduction

Terrestrial arthropods are extremely important ecosystem components. They exert control over the stability and functioning of ecosystems, are key players in nutrient cycling and also create substantial economic value via ecosystem services such as pollination (Pyle *et al*. 1981). Moreover, terrestrial arthropods are by far the most diverse group of organisms on our planet, as insects alone account for an estimated 57% of all species living on our planet (Millennium Ecosystem Assessment 2005).

The best approach to collect the wide range of terrestrial arthropods has been a topic of long-lasting debates (Greenslade and Greenslade 1964; Townes 1972; Shepard *et al*. 1974; Basset 1988; Coddington *et al*. 1991; Brehm and Axmacher 2006). When selecting an appropriate sampling method, one should closely consider the design of the respective sampling tools and their costs, as well as the ecological traits and habitat conditions of the target taxa (Gullan and Cranston 2005). Specific sampling methods are indeed needed to sample different arthropod taxa. For example, pitfall traps are highly useful for ground-dwelling beetles and ants, malaise traps for flies or parasitic wasps, light traps for moths and many other nocturnal insects, and window traps for Staphylinidae and Scarabaeidae (Bowden and Church 1973; Kitching *et al*. 2001). The capture effectiveness of sampling methods and their improvements are continually studied (Gressitt and Gressitt 1962; Shepard *et al*. 1974; Luff 1975; Peck and Davies 1980; Masner and Goulet 1981; Oliver and Beattie 1996; Campos *et al*. 2000; Axmacher and Fiedler 2004; Sabu and Shiju 2010).

Some papers refer to "active" and "passive" sampling as methods with or without human power when collecting specimens (e.g. Gullan and Cranston 2005). Here, active and passive sampling is used in a slightly different way, distinguishing if an attractant is used to sample specimens or not. Sampling methods are overall divided into three different categories: passive sampling methods without any "activity density" bias, for example collection of leaf litter or soil samples, sweep netting and knockdown by chemical fogging; passive sampling methods with an "activity density" bias, for example pitfall traps, sticky traps, suction traps, Malaise traps and window traps; and finally active sampling methods with inherent "activity density" bias. All respective methods use an additional attractant that often adds an additional

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bias to the sampling results due to a differentiation in the response of individual species to the specific attractant. This latter group includes for example light traps, pan traps, bait traps and highly specific pheromone traps.

This review will provide a brief overview of common sampling methods for terrestrial arthropod assemblages used in biodiversity studies and pest control, discussing their individual advantages and shortcomings.

2 Terrestrial arthropods sampling methods

2.1 Passive sampling methods without "activity density" bias

2.1.1 Berlese-Tullgren funnel for soil samples

To extract micro-arthropods inhabiting the soil, a Berlese-Tullgren funnel (Southwood and Henderson 2000) has been widely used (e.g. Harris 1971). A soil core of standardized volume is taken by for example a bulb planter or metal ring. Soil cores are then moved into a funnel, where a temperature gradient is created by heating sources like 100-W light bulbs, which causes living arthropods to move from the warmer side to the cooler side of the funnel and finally into the collecting bottle of this device. The apparatus has been further improved by Macfadyen (1955, 1961), allowing the control of not only temperature, but also humidity to increasing its effectiveness. Sample extraction using this method is comparatively easy (Basset *et al*. 1997). However, soil samples need to be processed quickly to avoid death of specimens, as it is based on the soil micro-arthropods moving actively through the soil column.

2.1.2 Leaf litter collection

Leaf litter collecting is mainly used to sample ground-dwelling microarthropods and beetles. In this approach, the complete litter layer on top of the mineral soil is normally collected over a standardized area. Leaf litter arthropods can then be extracted with Berlese-Tullgren funnels (Crossley and Hoglund 1962) or with litter-washing, where specimens appear on the water surface when litter is positioned in a water-filled tray (Spence and Niemelä 1994). This is a very inexpensive method, but often relative destructive as large amounts of litter are often required to sample sufficient numbers of specimens, which is also highly time-consuming. Again, leaf litter washing requires dealing with the samples quickly to avoid the death of specimen. However, leaf litter sampling can form a good composite technique with pitfall trapping, as specimen with small body size rarely appear in the latter (Olson 1991; Spence and Niemelä 1994).

2.1.3 Netting

Butterfly and sweep nets are two common net types used in terrestrial arthropod sampling. Butterfly nets are used to capture insects flying or hovering over foliage, for example butterflies, bees and hoverflies. A common butterfly net consists of a handle and a fine mesh kept open by a metal hoop. The length of the handle and the diameter of the net mouth can be varied to take account of the agility of target insects and the type of habitat, with a longer handle and wider mouth required for fast-moving and larger insects. In this type of net, the bag is generally deeper than its diameter (Gullan and Cranston 2005). The structure of sweep nets is similar with butterfly nets, but as these nets are actually used to "sweep" arthropods off the vegetation, they are made up of more solid and durable materials such as cotton or linen. They are mainly used to catch insects hiding in low grass- or herb-dominated vegetation and in small shrubs.

Netting is a highly cost-effective and rather non-intrusive method. This approach is very useful when comparing the relative species abundance and richness of small, vegetation-dwelling arthropods between different areas with similar vegetation types (Evans *et al*. 1983; Siemann *et al*. 1997). However, the capture rate of netting highly depends on the collector's skills, and particular butterfly netting has an inherent bias related to the speed and activity pattern of the specimens. It is also a time-consuming method which is most suitable for open habitat types such as grass- and bushland, but not easy to standardize in forest environments with high vegetation density. Moreover, netting is normally carried out at day time as it requires a good vision, thus causing some limitation to its wider applicability, e.g. for catching nocturnal taxa (Cane *et al*. 2000; Bartholomew and Prowell 2005; Roulston *et al*. 2007).

2.1.4 Canopy fogging

Knockdown of arthropods from vegetation using an insecticide fog is used mainly in samples of arboreal arthropods (Basset *et al*. 1997). Insecticide fog can be sprayed into the tree canopy directly from the ground or distributed directly into tree crowns, while in larger-scale sampling, and even planes are sometimes used to distribute the insecticide (Adis *et al*. 1998). Arthropods falling from the trees are collected in big plastic trays or nets (e.g. $1m^2$, Allison *et al*. 1993) beneath the trees.

Fogging is a time-effective method which can assemble comprehensive arthropod samples of taxa living in tree canopies (Erwin 1983; Paarmann and Stork 1987; Basset *et al*. 1997; Yanoviak *et al*. 2003). Fogging can cause low rates of death depending on the type and concentration of insecticides used (Paarmann and Stork 1987). The shortcomings of this method include the need of a clam weather condition; difficulties in assessing the correct amount of insecticide to be used as it is difficult to estimate the number and density of target specimens; resampling of the same trees is problematic and the approach is not very effective in sampling particular microarthropods like Acarina or Collembola, and of species living in microhabitats like bark crevices, epiphytes and tree holes (Basset *et al*. 1997; Yanoviak *et al*. 2003). Depending on the type of insecticide used, this method can also be highly destructive to arthropod communities.

2.2 Passive sampling methods with "activity density" bias

2.2.1 Pitfall traps

A pitfall trap consists of a container buried in the ground with its rim at surface level, and often with a roof above the trap to limit evaporation and dilution of killing liquids by rain water. There are a variety sizes and designs of pitfall traps. The diameter of the container varies between 2 cm and 2 m and contains different volumes, with container materials ranging from glass and plastic to mental (Greenslade 1964; Hinds and Rickard 1973; Luff 1975; Oliver and Beattie 1996). In ground arthropod sampling, liquids are usually added to kill the samples and preserve them. Killing liquids usually cover the bottom of the container, ensuring that the samples are easier to identify after prolonged sampling periods and limiting their chance to escape (Pekar 2002). Solutions commonly used are water saturated with salt, diluted formaldehyde, ethylene glycol, benzoic acid and alcohol. It should be added that the use of strong volatility chemicals like alcohol can be controversial for a standard 'passive' sampling method as it actively attracts certain species like molluscs, but we still consider pitfalls as passive traps because the solutions are mainly used to preserve samples rather than attracting them. In water-based solutions, a little detergent is often added to lower the surface tension and prevent insects from floating on the surface (Gullan and Cranston 2005). In addition to wet pitfall traps which contain liquids, dry pitfall traps are also sometimes used, which capture living samples (Mader *et al*. 1990; Winder *et al*. 2001).

As cost-effective sampling methods, pitfall traps are widely used in collecting surface-dwelling arthropods (Greenslade 1964; Baars 1979; Olive and Beattie 1996; Liu *et al*. 2006; Sabu and Shiju 2010), sometimes even as the standard method for selected species assemblages (e.g. for carabids, see Rainio and Niemelä 2003). The capture results are affected by the structure of the ground vegetation (for example, catches of ground beetles can be reduced with the increase of vegetation height, Greenslade 1964), trap size (with small traps more efficient in catching small beetles, while large trap in catching larger ones, Luff 1975), trap shape (with round traps catching more carabids than rectangular ones, Spence and Niemelä 1994), material of the trap (with glass being the most capture-effective material in catching beetles as compared to plastic and metal, Luff 1975), solution concentration (with the concentration of formaldehyde positively correlated with the capture rate of carabids, Pekar 2002), detergent (for example the number of spiders caught increases with the addition of detergent, Pekar 2002) and cover use (more carabids caught in traps without cover than in those with covers, Spence and Niemelä 1994). Therefore, when using pitfall traps to study a certain arthropod taxon, a good combination of trap designs should be considered. For example, round glass traps with 20% formaldehyde and without cover would be effective traps for catching carabids.

Pitfall traps are obviously suitable to sample mobile, ground-dwelling arthropods, but not arboreal or primarily "airborne" ones (Spence and Niemelä 1994; Siemann *et al*. 1997; Rainio and Niemelä 2003). In addition, pitfall traps catch mammals (e.g. mice), amphibians (e.g. frogs) and slugs, which rot quickly with bad smell, affecting catches of target arthropods. Predation of sampled insects by birds or predatory carabid beetles and other predatory insects inside the containers can also influence to composition of pitfall trap samples (Mitchell 1963).

2.2.2 Sticky traps

Sticky traps have been widely used in pest monitoring and arthropod sampling (Harris *et al*. 1971; Williams 1973; Midgarden *et al*. 1993; Basset *et al*. 1997; Atakan and Canhilal 2004). They usually contain a cardboard coated with sticky glue on the surface to catch target specimens touching it. The height at which the trap is installed strongly affects catching results. For example, western flower thrips are most effectively caught at 2.4 m above the ground (Gillespiel and Vernonz 1990). Traditional sticky traps are generally considered to be passive sampling methods, but they often are coloured specifically to attract certain arthropod taxa. Fruit flies, aphids, whiteflies and leafhoppers for example are all effectively attracted by yellow traps (Atakan and Canhilal 2004), whereas translucent or white traps are more effective than red and black ones in collecting flies (Williams 1973) and blue shades are more effective than white and yellow ones for western flower thrips (Brødsgaard 1989).

Sticky traps are highly cost effective and can be used with many replicates in a certain area, but glues are hard to remove from specimens and would potentially damage them (Basset *et al*. 1997).

2.2.3 Suction traps

Suction traps are devices using a flow of air led over a net to catch arthropods. There are two main types of suction traps: the Johnson-Taylor suction trap and the Dietrick vacuum insect net (D-vac). Johnson-Taylor (Johnson 1950; Taylor 1951) suction traps are mainly used in catching aerial arthropod. The trap mainly consists of a suction tube and an exhaust box. The exhaust box consists of an electric fan and a net attached over the collection jar. Air is extracted from the box when the fan is working, resulting in a partial vacuum and the rapid flow of air through the sampling tube. Thus, arthropods are moved into the collection jar. To reduce damages for arthropods caused by fast air flow in the tube, there usually is an expanded buffer area connected between the tube and the net. The D-vac (Dietick *et al*. 1960) suction trap uses a motor fan and is mainly used for the sampling of ground active arthropods. It usually consists of a motorized electric exhaust fan and a nylon collection net. The mouth of the net is fixed on a circular metal hoop, while the bottom is connected to the fan. When sampling, the hoop part is fixed to the ground, covering the target area from which the fan sucks the air.

Suction traps are particular useful in monitoring agricultural insects. They are a high efficient method which allows the sampling of a relatively large area within a short time period and are also useful for long-term arthropod monitoring. Disadvantages are that they are expensive per unit and are often bulky and therefore inconvenient for transport and work in remote areas.

2.2.4 Malaise traps

Malaise traps are an effective type of flight-interception traps invented by R. Malaise (1937). Several varieties are currently in use (Gressitt and Gressitt 1962; Marston 1965; Townes 1972; Masner and Goulet 1981; Steyskal 1981), but the basic structure consists of a tent with a large opening at the front and back and a fabric barrier in the centre to intercept flying insects. Intercepted insects fly upward and become trapped in the top of the trap in a collecting jar often filled with a killing agent (see Campos *et al*. 2000). In placing Malaise traps, the flight behaviour of the selected target taxa and local circumstances such as topography, density of vegetation, wind and water conditions need to be taken into consideration (Gressitt and Gressitt 1962).

The Malaise trap is an easy-to-make, low cost sampling tool which can capture flying arthropods day and night, especially when additionally being illuminated at night (Gressitt and Gressitt 1962; Basset 1988; Campos *et al*. 2000). It is commonly used in sampling of Hymenoptera, Diptera, Thysanoptera and Coleoptera (Peck and Davis 1980; Darling and Packer 1988; Strickler and Walker 1993; Olsen and Midtgaard 1996; Campos *et al*. 2000). Limitation of Malaise traps are that they are confined to the sampling of flight-active arthropods, have a comparatively low trapping effectiveness which sometimes may cause statistical problems, and in the trap equipment becoming easily damaged by wind, especially in long-term studies (Basset 1988).

2.2.5 Window traps

A window trap is another type of flight interception trap, based on similar principles to the Malaise trap. It was first introduced by Chapman and Kinghorn (1955) and later modified for example by Peck and Davies (1980). The construction of a window trap includes a pane of glass, perspex, silk or fine mesh which is considered invisible to the target arthropods. This pane or net is located in the centre of a suspected flight path as a barrier to arthropods using this path, and a container or gutter filled with liquid preservatives is placed beneath the net (Fig. 1). Flying arthropods are collected once they fall into the preserving liquid after hitting the barrier. A roof is added on the top if the trap needs to resist rain.

Window trapping is an easily standardized, replicable sampling method and can capture large quantities of flying arthropods (Bouget *et al*. 2008). Small-scale diversity patterns are not always well reflected in samples from window trap (Jonsson *et al*. 1986). The efficiency of window traps is also affected by the material of the barrier, with large beetles flying at high speed potentially bouncing off hard barriers without falling into the sampling containers below (Boiteau 2000). The exact shape, silhouette and height of the barrier also has a strong influence on sampling efficiency (Bouget *et al*. 2008), as has the exact placement of the trap. Disadvantages of window traps include that they catch only flying arthropods, they are relatively expensive per unit especially in traps using hard barriers, can be easily damaged by high winds, have a relatively small flight interception area, and often suffer additional problems relating to the efficient installation and sample retrieval, and logistical problems can occur when sampling is to occur in the forest canopy (Peck and Davies 1980; Carrel 2002; Gullan and Cranston 2005; Bouget *et al*. 2008).

2.3 Active sampling methods

2.3.1 Light traps

Nocturnal arthropods like many species of moths and beetles are easily attracted by artificial light sources (Nag and Nath 1991; Axmacher and Fiedler 2004). Light traps have therefore been widely used in nocturnal insect sampling for a long time (e.g. Ricklefs 1975; Morton *et al*. 1981; Thomas 1996; Holyoak *et al*. 1997; Axmacher *et al*. 2004a, b).

Many light traps are often relatively expensive, but robust sampling devices which can collect high numbers of specimens (Basset *et al*. 1997; Liu *et al*. 2007). Light sources vary greatly, ranging from gas lamps to mercury vapour lamps and fluorescent UV light tubes, and collection of samples can either be manual or automatically (Brehm and Axmacher 2006). There basically are two types of light trapping devices: "light towers" or more basic devices

Fig. 1 A window trap using black silk mesh of 1.5 m x 3 m with a plastic roof in the Korean Pine forest of Changbai Mountain, Jilin Province, China. Photo: ZOU Yi.

such as white sheets spread behind light sources which are suitable for selective, manual collection, and automatic light traps. In the case of light towers, insects are collected in a jar equipped with a chemical to stun and kill the specimens after they land on the surface of the light tower. Alternative setups use a simple white sheet placed behind the light source. In automatic trap, insects are sampled after they are attracted towards transparent vanes, sliding down through a funnel where killing agents can be applied (Brehm and Axmacher 2006).

The capture rates of light traps are highly variable and affected by a wide array of factors relating to the trap design and environmental conditions. Sampling success is affected for example by the above-ground height of the light source and the type of trap illumination (Baker and Sadovy 1978; Bowden 1982), and attraction also varies between species (Bowden 1982). The timing of light traps should also consider effects of background illumination by moonlight or anthropogenic light sources (Bowden and Church 1973; Morton *et al*. 1981; Bowden 1982; Nag and Nath 1991; Nowinszky 2004). Light traps are highly effective and can preserve specimen in relatively good state, which is very important for sampling relatively frail specimens such as small moths. The disadvantages of light traps include their limitation to nocturnal species, and difficulties in direct comparisons of quantitative data due to differences in light attraction between taxa (Basset 1988). Traps are also often heavy and inconvenient to carry in remote areas. In addition, specimen can become damaged by large, active species or when large sample sizes are caught in the traps (personal experience).

2.3.2 Pan traps

Pan traps, also referred to as “water traps”, show many similarities to pitfall traps, but are generally operated above the soil surface (Cane *et al*. 2000). Pan traps are plastic bowls commonly filled with water, with a few drops of dishwasher detergent added to break the surface tension. Target insects will sink into the water when they land on the surface. Different colours can again significantly affect the capture rate for different arthropod taxa. For example, yellow pans are used in studies of diverse groups of pollinators (Leong and Thorp 1999; Kitching *et al*. 2001), while blue pan traps are more effective in catching Stephanidae in comparison to yellow ones (Aguiar and Sharkov 1997) and red pans are attractive for *Amphicoma* beetles (Dafni *et al*. 1990) while white is more attractive than yellow for many dipterans (Disney *et al*. 1982). Responses to traps differ between sexes (Leong and Thorp 1999), which needs to be taken into consideration during general surveys.

Pan traps are effective in capturing a wide range of insect taxa such as flower-visiting flies and skippers, and they are very useful to record bee species (Leong and Thorp 1999; Cane *et al*. 2000; Roulston *et al*. 2007). Pan traps are a cheap and easily transportable sampling tool. They are sensitive to rainfall and thereby need to be regularly checked.

2.3.3 Bait traps

The term bait trap refers to a wide range of active taps usually using potential food items as attractants and can be combined with other trapping methods. While traditional mouse-traps are an examples for bait traps used in mammal catches, baited traps are also commonly used in arthropod surveys. Examples of bait range from syrup used in pitfall traps as an effective attractant for ants (Greenslade and Greenslade 1971) to vinegar-sugar alcohol-water mixtures as effective bait for carabids (Yu *et al*. 2006) in pitfall traps. White bread is attractive food for cockroach sampling (Ballard and Gold 1982) and rotting bananas, molasses and rum are used in attracting butterflies (Hughes *et al*. 1998). Bait traps are effective sampling methods for live catches of arthropods. The selection of food source is of crucial importance, so basic knowledge of feeding habits is a prerequisite to use this method.

2.3.4 Pheromone traps

Pheromones are semiochemicals released by species that can cause certain behavioural or physiological responses of other individuals. Pheromone traps are widely used in monitoring arthropods population for pest control. Sex pheromones and aggregating pheromones are the main two types of pheromones used in these traps. Sex pheromones are semiochemicals that sexually maturity specimens produce to attract the opposite sex for mating while aggregating pheromones are produced by species to induce gathering for feeding or attack. Pheromone traps are high selective for certain species and often gender, and they are widely used in the trapping of Lepidoptera and Coleoptera (e.g. Bell *et al*. 1972; Riedl *et al*. 1976; Mullen 1992; Turchin and Odendaal 1996; Walker *et al*. 2003). Pheromone traps are an inexpensive and easily implemented approach in many cases, although the initial production of specific pheromones can be expensive and time-consuming. They are usually weather sensitive and often require substantial knowledge of the target species (Weinzierl *et al*. 2006).

3 Comparisons

As demonstrated above, different sampling methods need to be used for different arthropod taxa, with appropriate sampling techniques being key for effective arthropod monitoring, pest control and biodiversity research. For sampling methods with an inherent ‘activity density’ bias which are therefore depended on both population densities and activity patterns of individual species, it is important to acknowledge that respective samples will not normally reflect the species’ prevailing density, and short-term shifts for example in weather conditions can alter results substantially. In biodiversity studies, we recommended to use diversity indices which are robust for resulting

Table 1 Comparisons among different terrestrial arthropods sampling methods.

Sampling method	Attractant (passive/ active)	Activity density bias (+/-)	Targets	Advantages	Limitations
Soil extraction	Passive	-	Soil microarthropods	Inexpensive	Samples need to be processed quickly
Leaf litter collection	Passive	-	Ground-dwelling microarthropods	Inexpensive	Samples need to be processed quickly; large amounts of litter needed
Netting	Passive	-	Flying arthropods, arthropods sitting in vegetation	Inexpensive; non-intrusive	Labourious
Canopy fogging	Passive	-	Arboreal arthropods	Time effective; highly productive	Weather sensitive; non-repeatable
Pitfall traps	Passive	+	Ground-dwelling arthropods	Inexpensive	By catch of mammals, amphibians and slugs; predation by birds and predatory insects
Sticky traps	Passive	+	Flying arthropods	Inexpensive	Specimen are difficult to extract from the sampling device
Suction traps	Passive	+	Aerial and ground-dwelling arthropods	Highly effective	Expensive; difficult to transport
Malaise traps	Passive	+	Flying arthropods	Inexpensive	Low trapping effectiveness; easily damaged by wind
Window traps	Passive	+	Flying arthropods	Easily standardized; replicable; highly effective	Easily damaged by wind, small flight interception area
Light traps	Active	+	Nocturnal arthropods	Highly effective	Expensive, potential damage of specimen
Pan traps	Active	+	Flower-visiting arthropods	Inexpensive	Sensitive to rainfall
Bait traps	Active	+	Specific groups or species	Highly effective	Bait can be difficult to handle
Pheromone traps	Active	+	Specific groups or species	Highly effective	Weather sensitive; need substantial knowledge of the target species

differences in samples like Fisher's α (Alpha of the log series, see e.g. Brehm *et al*. 2003; Axmacher *et al*. 2004a; Liu *et al*. 2006).

Table 1 provides a brief comparison of sampling methods for terrestrial arthropods described in this review. Active methods here refer to sampling arthropods with attractant that often work specifically for selected taxa. For pest control management, such targeted active methods are often more suitable than passive methods, for example when controlling the populations of pest species in Lepidoptera and Coleoptera using, for example, sex pheromones. Bait and pheromones can be combined with different trap types, for example in baited pitfall traps or pheromone-malaise traps, or they can also be used together to maximize sampling rates, with examples including sticky traps with additional food attractants or the use of male sex pheromones and female aggregation pheromones for the control of the olive fruit flies (Diptera, *Tephritidae*) (Haniotakis 1991).Some passive sampling methods are also used in pest controls because they are very robust in catching a large amount of pests, for instance in the use of suction traps in agricultural pest control (Hoyt and Burts 1974).

In biodiversity studies, sampling methods yielding large amounts of specimens while keeping them in appropriate condition for identification is an ideal approach. Nonetheless, a high sample volume is often correlated with a high proportion of damaged individuals. Window traps and Malaise traps are similar in constructions and can both be used to sample flying arthropods in high numbers. Compared with Malaise traps, window traps have much higher yields. However, Malaise traps are more suitable to be used with additional attractants to catch specific taxa. Both methods require an open area and can only trap targets on their flying path. Thus, sweep netting is a good complementary approach, also allowing for the catching of vegetation-dwelling arthropods. They can also be used to supplement light traps, where the type of light and trap design again strongly influence both sample volume and quality of the resulting specimens.

As results from different sampling methods yield strongly differing results, the combination of different methods is highly recommended for comprehensively sampling of larger taxa where different species often vary strongly in their behaviour and ecological niche. For example, pitfall traps are considered to be a standard method for the sampling of carabids (Rainio and Niemelä 2003), but they are strongly biased towards ground-dwelling ground beetles with a large body-size, so that complementary catches with light towers can generate a much better impression of the overall assemblage structure and species richness of a habitat (Liu *et al*. 2007). To record ground-dwelling carabids with a small body size (e.g. cryptozoic beetles) that are rarely recorded in pitfall traps (Olson 1994), leaf litter collecting is also very useful. In addition, window trap can catch day-flying carabids (e.g. *Amara* spp.). Further combinations can further enhance sampling success, for example with light towers placed behind window traps, combining as a window-light trap, ideal in sampling of a very wide range of flying beetle taxa (Huizen 1980).

Among all sampling methods mentioned above, canopy fogging, sticky traps, window traps and pan traps usually kill specimen, and therefore not suitable for monitoring rare species. Other methods such as pitfall traps and Malaise traps can keep specimen alive if no killing solution is added in the collection containers. In addition, pitfall traps, sticky traps, Malaise traps, window traps and pan traps are easily used in the long-term continuously monitoring, while others such as soil extraction, leaf litter collection, netting and canopy fogging are generally used for selecting certain samples and could be influenced by collectors' skills. Suction traps and light traps can also be used in long-term continuously monitoring if proper electric power can be provided. Moreover, it should be kept in mind that some methods like canopy fogging can be highly detrimental to the arthropod populations within the study area and potentially even in areas in their vicinity, indiscriminately killing a wide range of species. These techniques should therefore be avoided in sensitive habitats known to harbour threatened species.

In conclusion, how to select a proper sampling method depends on the sampling purpose. The basic knowledge of target arthropods' habits is required before starting sampling. None of a single method is panacea for collecting a wide range of arthropod taxa. Therefore, a good combination of different methods is highly recommended for ecological surveys.

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陆生节肢动物采集方法比较

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摘　要：陆生节肢动物是生态系统的十分重要组成部分。面对广泛分布的陆生节肢动物，如何选择最合适采集方法是长期以来被探讨的话题。本文介绍了一些常用的陆生节肢动物采集方法。 我们将其分为三大类：有“活动密度”缺点的被动采集方法，无“活动密度”缺点的被动采集方法以及带有内在“活动密度”缺点的主动采集方法，并探讨了各种方法的优缺点，为生物多样性研究以及病虫害防治工作提供了基础。如何选择合适的采集方法主要取决与采集的目的以及目标物种的生活习性，在大多数情况下，多种不同的采集方法组合将会有较好的效果。

关键词：陆生节肢动物；采集方法；比较；活动密度