Learning Objectives

• Define the appropriateness of the term “carnivore” for carnivorous plants.
• Compare carnivorous plants to protocarnivorous plants.
• Describe and give examples of five types of traps developed by carnivorous plants.
• Analyze the costs and benefits of plant carnivory to determine conditions under which carnivory is adaptive.
Carnivorous Plants: Competing for Nutrients

The idea of a plant eating an animal has always fascinated people, from “pet” Venus Flytraps (Figure 1.1) to “Audrey, Jr.” in the Broadway musical, Little Shop of Horrors - or the Whomping Willow of the Harry Potter series. Inevitably, intrigued biology students suggest that such unique plants play the role of consumers, rather than producers, in their ecosystems. Indeed, the general name for this group of plants - carnivore - supports this hypothesis. However, no known plant obtains a majority of its energy from the animals - usually insects, other arthropods, or protozoa - it “eats”. What are the benefits of carnivory among plants? What kinds of adaptations allow plants to capture animals? These questions are the focus of this last section of the plant adaptations lesson.

Carnivorous “behavior” is clearly adaptive in some way; it is surprisingly common among plants. About 625 species are truly carnivorous plants (usually insectivorous plants) - able to attract and trap prey, secrete digestive enzymes, and absorb digested nutrients. Some 300 more are protocarnivorous plants, able to trap and kill prey but lacking either enzymes or the ability to absorb the nutrients. True carnivory may have evolved independently in ten different plant groups, now characterizing 12 genera in 5 families. Types of traps fall into five basic categories:

1. Pitfall Traps
2. Flypaper Traps
3. Snap Traps
4. Bladder Traps
5. Lobster-pot Traps

Pitfall Traps

Pitfall Traps are modified, rolled leaves, sealed at their edges, which contain a pool of digestive enzymes and/or bacteria.

Pitcher plants are well-known New World examples - perhaps the simplest of the pitfall varieties. The South American marsh pitcher (Figure 1.2) has rolled leaves that trap water and harbor symbiotic bacteria which secrete the necessary digestive enzymes. A “nectar spoon” secretes sugars, which attract insect prey, and downward pointing hairs restrict their exit. Slippery, waxy flakes line the cups, helping to prevent prey escape. An overflow slit maintains a constant level of water.

The dramatic Cobra Lily (Figure 1.2) shelters its pitcher from rainfall with a large, mottled hood and two “fangs”. Cobra lilies do not secrete digestive enzymes, but rely on bacteria to break down prey. Lining cells identical to root cells absorb the bacteria-digested nutrients. Mottled coloration creates patterns of light, which appear to prey as “false exits”; the insects finally tire of trying to find a way out, and fall into the trap.

The largest pitcher plants are monkey cups of the genus Nepenthes. N. rajah (Figure 1.2) inhabits serpentine soils, low in nitrogen, phosphorus and calcium/magnesium and toxic to many plant species. N. rajah produces a huge urn up to 40 cm (16 in) tall, 18 cm (7 in) wide, and 2.5 liters (2/3 gallon) in volume of digestive fluid. This vine-like
species suspends its urns from strong “tendrils”, but larger urns rest on the ground. Nectar-secreting glands cover the pitcher, and digestive glands line the interior. *N. rajah* is famous for trapping small birds, reptiles, and mammals, although its main “diet” is insects. A number of species of insects, spider, and even a crab inhabit the urn safe from digestion; some are not known to survive anywhere except in this species. Many biologists believe that these symbioses are mutually beneficial; the animals receive habitat, protection, and prey, and the plant receives help with digestion, reduced bacteria, and increased nutrient availability.

**Flypaper Traps**

*Flypaper Traps* coat leaves or hairs with sticky substances. Butterworts, sundews, and rainbow plants secrete gooey, polar glycoproteins to attract and trap prey.

In *butterworts* (Figure 1.3), abundant tiny, stalked glands make the leaf shiny with secreted mucilage, which lures and captures small gnats. The leaves respond to the stimulus of prey touch by secreting more mucilage and growing curled edges which form digestive depressions and limit rain splash. Insect entrapment stimulates a second set of glands to release digestive enzymes. Digested nutrients are absorbed through openings in the cuticle, which require that the plant live in humid habitats. Butterworts have reduced roots to anchor the plant, because the insects provide nutrients. Stalks produce flowers at some distance from the carnivorous leaves - so as not to risk digesting pollinators! Some species form non-carnivorous leaves during dry and/or cold seasons, reducing energy costs when benefits are few.
Butterworts (above) and sundews (below) produce glycoprotein “flypaper” to lure and trap insects. Both plants respond to the presence of insects by curling and secreting digestive enzymes; sundews move their “tentacles” as well as their leaves.

Over 100 species of sundews (Figure 1.3, lower photos), with diameters ranging from 1 cm to over a meter and habitats from bogs to gravel pits, trap and digest insects in a manner very similar to that of butterworts. Their mucilage glands, however, are much more prominent, raised on long stalks or “tentacles”, and specialized surface glands absorb digested prey. Both tentacles and leaves are highly mobile; tentacles can curl around prey in seconds, and leaves can grow around prey in as little as 30 minutes. Many sundews depend so completely on insect prey for nitrogen that they no longer produce the nitrate-metabolizing enzymes of traditional plants, and their roots are reduced to simple anchoring structures.

Snap Traps

*Snap Traps* catch prey with rapid leaf movements.

Only two species have the ability to move quickly enough to be categorized as “snap traps”. *Venus fly trap* (Figure 1.1 and Figure 1.4) is easily the best known. Two-part leaves are modified for photosynthesis (the petiole is broad and flat) and for insect-catching (the tips of the leaves develop into the famous traps). Three hair-like trichomes on each of the two trap surfaces are so sensitive that they can distinguish between raindrops and prey: if two trigger hairs are touched in succession, or one touched twice, an action potential/ion flow similar to the one that causes your muscles to contract closes the trap within 1/10th second. The exact mechanism is not understood, but some combination of osmosis, pH change, and ion flow causes the two sides of the trap to “snap” from convex to concave. Fringes of stiff hairs mesh, preventing the prey’s escape. Secreted enzymes digest prey over a period of ten days,
and then the trap opens again. By some estimates, each trap catches only 3 insects per lifetime.

*Figure 1.4*

Just two species deploy “snap traps” to catch prey: the terrestrial Venus fly trap (top two photos) and the aquatic Waterwheel Plant (lower left). Although the mechanism for closing the traps (within 1/10th sec for Venus fly trap and 0.01-0.02 sec for Waterwheel) remains incompletely understood, it is known to involve sophisticated triggers (bottom right) which react to touch.

*Waterwheel Plant* is an underwater version (although a different genus) of Venus fly trap. Floating stems 7-11 cm (2½ - 4 in) long support whorls of paddle-like leaves which closely resemble those of the fly trap, although these traps are lined with many trigger hairs, rather than just 3, and a set of bristles protects the hairs from false triggering. This trap closes within 0.01-0.02 sec, one of the fastest examples of movement in the Plant Kingdom. Like other carnivorous plants, this plant switches to non-carnivorous leaves in winter, sinking to the bottom of the pond where temperatures are warmer. As temperatures rise in spring, the plant begins to secrete buoyant gases, rises to the surface, and re-grows its carnivorous leaves.

**Bladder Traps**

*Bladder Traps* create internal vacuums, which suck in prey.

A single genus containing 251 species utilizes the bladder mechanism to suck prey much as you would suck through a straw to drink milk or soda. You create a vacuum by contracting cheek muscles, but *bladderworts* (*Figure 1.5*) use active transport to pump ions out of their interiors, and depend on water to follow by osmosis. The bladder has a hinged flap or “door”, guarded by a pair of long trigger hairs. When an aquatic invertebrate brushes the hairs, the hairs act as levers, springing open the door so that the bladder “gulps” the prey by suction. When the bladder is full, the door closes - the whole process taking as little as 0.01-0.015 second. Aquatic species’ bladders are as long as 5 mm, able to trap aquatic invertebrates and even small tadpoles and fish fry. Terrestrial bladderworts prey on microscopic organisms such as protozoa and rotifers in wet soils. Perhaps 5% of bladderwort species are epiphytes, some living in bromeliads high in the canopies of tropical rain forests.

**Lobster-pot Traps**

*Lobster-pot Traps* prod prey toward a digestive organ with inward-pointing hairs.

Although many pitcher plants use some of the features of lobster-pot traps, these are secondary to the “pitcher”.
A lobster pot is a trap which is easy to enter, but difficult to escape, due to inward-pointing bristles or hairs. Corkscrew plants (Figure 1.6) of Africa, Madagascar, and Brazil use lobster pots as their primary mechanism, attracting protozoa by emitting chemicals. Underground traps are pairs of thin tubes with spiraling grooves, which guide soil invertebrates. Inward-pointing hairs prevent escape and force prey toward the middle of the tube, guiding them to the juncture of the two tubes and into a digestion chamber. One species in this genus, Genlisea margaretae, has the smallest known genome of any living plant: just 63.4 Megabase pairs.

We can gather evidence for the benefits of carnivory by looking for similarities among all of these species.

- Nearly all are green and capable of photosynthesis. Energy cannot be the sole reason - or even a major reason - for carnivory.
- Nearly all live in nutrient-poor or thin soils, such as acidic bogs, where sunlight and water are abundant. This commonality suggests that prey nutrients may allow carnivorous plants to out-compete plants with traditional root absorption of nutrients.

Detailed research supports this conclusion. Nutrients such as nitrogen (N), phosphorus (P), and potassium (K)
are essential to build proteins, nucleic acids, and cell walls, and to construct osmotic gradients. The efficiency of photosynthesis itself depends on adequate nitrogen and phosphorus to build enzymes such as RuBisCo. A cost-benefit analysis of carnivory shows that the energy gained from increased photosynthetic efficiency outweighs the energy required to build and operate carnivorous structures (including traps, glands, hairs, glue, and digestive enzymes) - if sunlight is abundant and nutrients are limiting. Study **Figure 1.7** (energy cost = respiration; energy gain = CO₂ uptake; net benefit (or loss) = net photosynthesis) to confirm this conclusion.

**Summary**

- Carnivorous plants trap, digest, and absorb nutrients from animals but rely on photosynthesis for energy.
- Protocarnivorous plants may trap insects and other animals, but cannot digest or absorb their nutrients.
- Five types of traps are pitchers, sticky surfaces; snap traps, bladder traps, and lobster traps.
- Energy benefits of carnivory outweigh cost only in habitats with abundant light and low nutrients, (bogs).
References

1. Left: Aidan Wojtas; Right: Derek Gavey. Left: https://www.flickr.com/photos/aidanwojtas/3302593111/; Right: https://www.flickr.com/photos/derekgavey/5069358550/. Left: CC BY 2.0; Right: CC BY 2.0


