

# Chapter 6

## Passive Capture Techniques

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### 6.1 INTRODUCTION

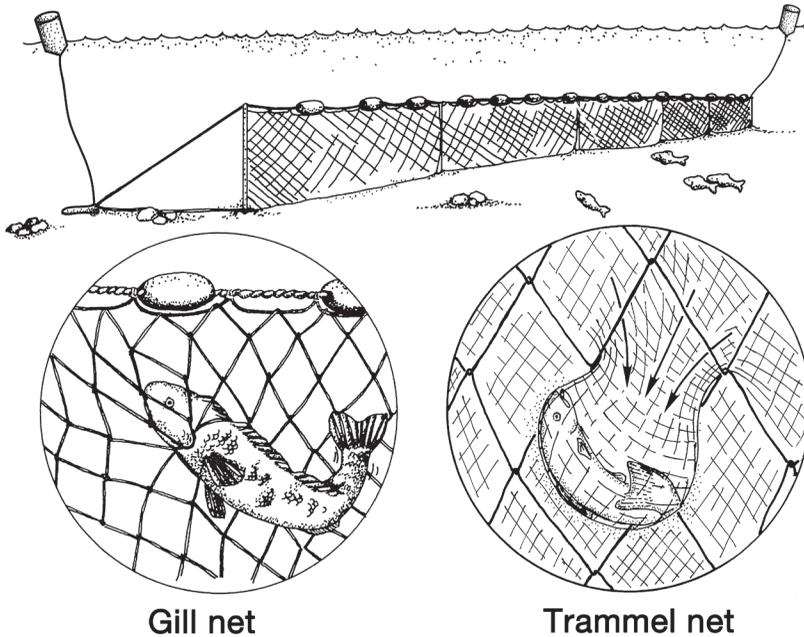
Passive capture techniques involve the capture of fishes or other aquatic animals by entanglement, entrapment, or angling devices that are not actively moved by humans or machines while the organisms are being captured (Lagler 1978). The behavior and movements of the animals themselves result in their capture. The techniques used in passive sampling of fish populations are similar to those used for food gathering over the centuries. Nets and traps have been widely used among various cultures, and many of the currently applied techniques were used by the ancient Egyptians, Greeks, and Romans (Alverson 1963).

Based on their mode of capture, passive sampling devices can be divided into three groups: (1) entanglement, (2) entrapment, and (3) angling gears. Entanglement devices capture fish by holding them ensnared or tangled in webbing or mesh made of natural or artificial materials. Gill nets and trammel nets are examples of entanglement gears (Figure 6.1). Entrapment devices capture organisms that enter an enclosed area through one or more funnel- or V-shaped openings that hinder escape after entrance. Hoop nets, trap nets, and pot devices are examples of entrapment gears (Figures 6.2 and 6.3). Angling devices capture fish with a baited hook and line. Trotlines and longlines are examples of passive angling gears (Figure 6.4).

Gear selectivity and gear efficiency are important considerations with respect to passive sampling devices. Often these terms are used interchangeably, but they have different, specific definitions. Gear selectivity is the bias of a sample obtained with a given gear (Box 6.1). Selectivity for species, sizes, and sexes of fishes occurs in samples taken with specific types of gear. Species selectivity refers to overrepresentation of particular species in samples as compared with the assemblage of species present. Similarly, size or sex selectivity refers to overrepresentation of specific sizes (lengths) or one sex within samples from a fish population. Fisheries scientists may use gear selectivity to their benefit when targeting specific species or sizes of fishes, thereby enhancing their sampling efficiency. The efficiency of a gear refers to the amount of effort expended to capture target organisms (Box 6.2). It is generally desirable to maximize the efficiency of a sampling gear to save time and money in single-species assessments of fisheries. Even with efficient sampling gear, the sampling effort needed to estimate the relative abundance and other descriptive statistics for a given species may be unrealistic (Gerow 2007).

#### 6.1.1 Advantages of Passive Gears

Passive gears are relatively simple in their design, construction, and use. They are generally handled without mechanized assistance other than a boat, and they require little specialized training to operate. Passive gears can be used to capture fishes for many purposes and can yield



**Figure 6.1** Two types of entanglement gears—a gill net and a trammel net—and illustration of a typical bottom set (modified from Dumont and Sundstrom 1961).

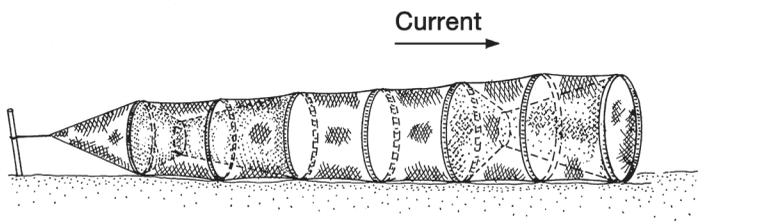
data on relative abundance for many species in many aquatic habitats. Identical types and designs of passive gear fished in a similar manner at the same time of year can provide reasonable indices of change in stock abundance (Box 6.3). A distinct advantage of many passive gears is that effort is easier to control than it is for most active gears. With passive gears, such as gill nets or trap nets, effort is generally expressed in terms of a “standard set” with a specific kind of gear and time interval. Presampling can be used to estimate sampling variability and sample sizes needed for management and research objectives (Parkinson et al. 1988; Gerow 2007).

### 6.1.2 Disadvantages of Passive Gears

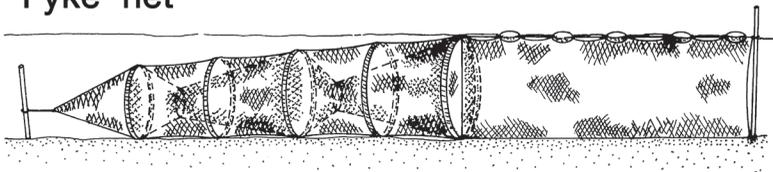
All passive sampling devices are selective for certain species, sizes, or sexes of animals. Commercial fishers who use passive gears apply their knowledge of gear selectivity to enhance the efficiency of catching targeted species of specific sizes (Carter 1954; Starrett and Barnickol 1955). The act of capturing an animal involves three steps: (1) the animal has to encounter the gear; (2) it must be caught by the gear; and (3) the animal needs to be retained by the gear until it is retrieved. Selectivity occurs at each step of the capture sequence. A quantitative understanding of gear selectivity is needed to interpret data from passive gears, but little information is available for most gears and target species.

Theoretically, the catch per unit effort ( $C/f$ ) of a passive gear should be directly proportional to the density of fish in the population, but relatively few studies have confirmed this assumption (Le Cren et al. 1977; Richards and Schnute 1986; Whitworth 1986; Schorr and Miranda 1991; Borgstrom 1992; McInerney and Cross 2006). Many variables in addition to population density contribute to variability in  $C/f$ . Important environmental variables

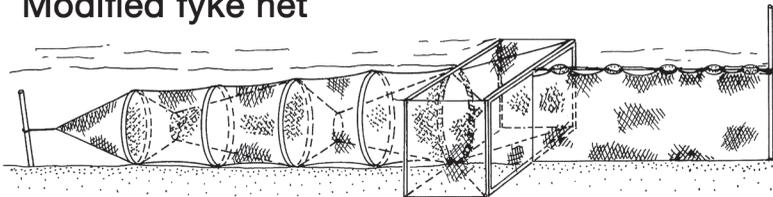
## Hoop net



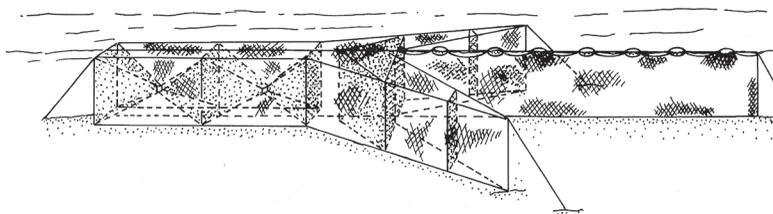
## Fyke net



## Modified fyke net



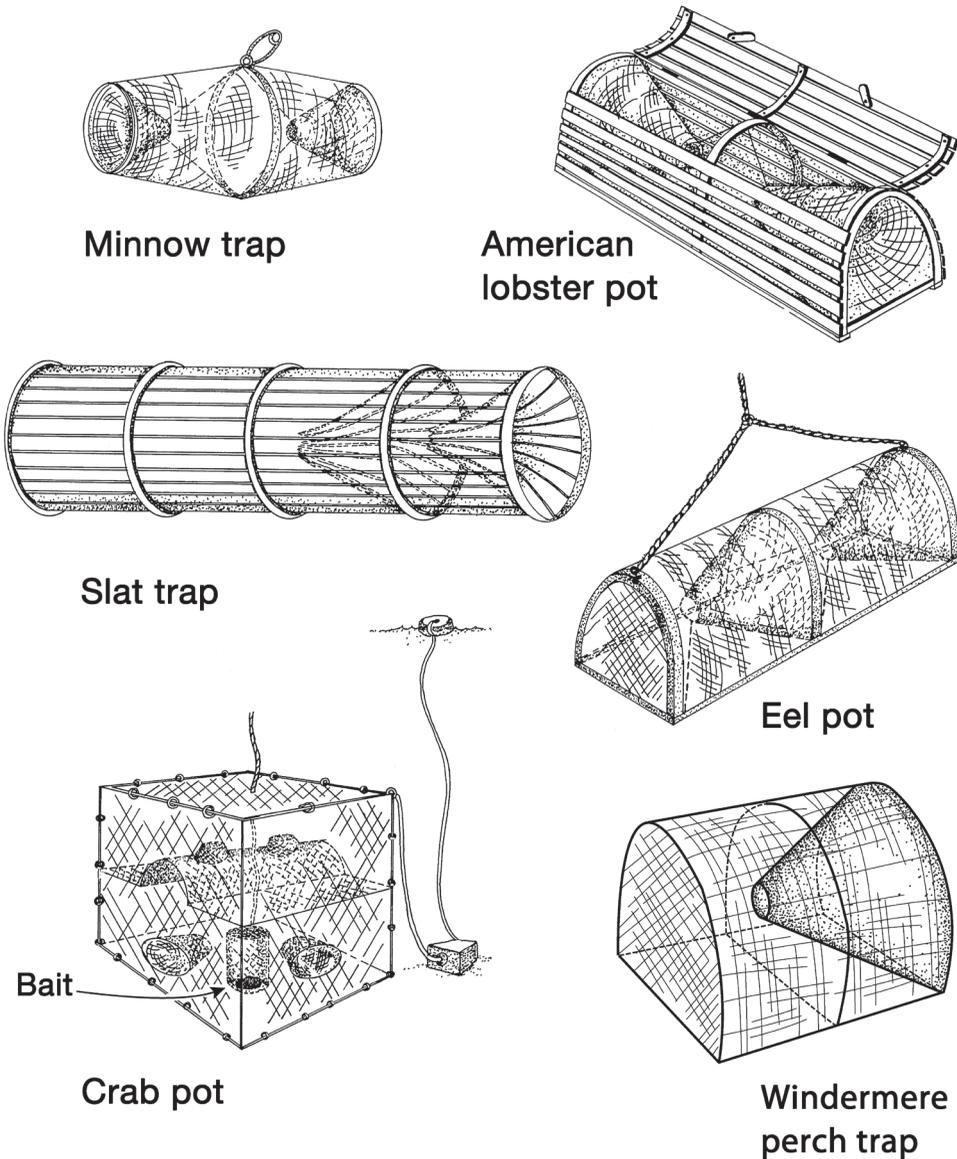
## Trap net



**Figure 6.2** Four types of entrapment gears—hoop net, fyke net, modified fyke net, and small trap net—and illustrations of typical bottom sets (modified from Crowe 1950 and Sundstrom 1957).

influencing  $C/f$  include season, water temperature, time of day (day or night), water-level fluctuation, turbidity, and currents. Behavior of fishes, such as schooling, migration, or crepuscular activity, also contributes to variation in  $C/f$  (Hubert and Fabrizio 2007). Whereas the assumption that  $C/f$  is directly proportional to absolute abundance ( $N$ ) of fish in a population is generally made, there are definable situations in which the assumption may not be valid (Box 6.4).

Differences in animal behavior and morphology lead to substantial variability in  $C/f$  among species and among age-groups within a species because animal capture with passive gear is a func-

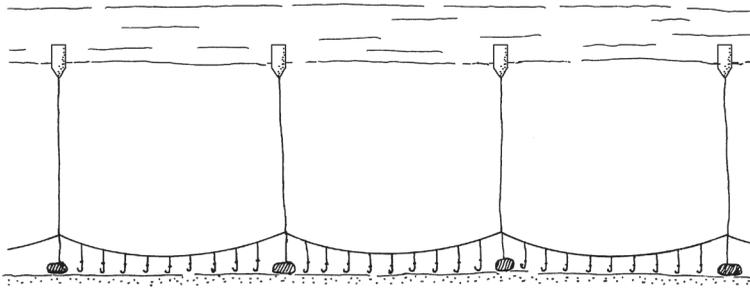


**Figure 6.3** Six pot gears used to capture fishes and crustaceans (modified from Sundstrom 1957).

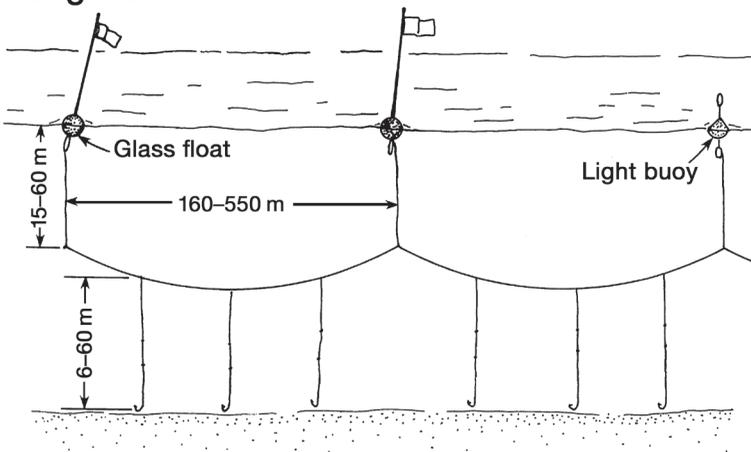
tion of animal movement and body form. Many movements are unpredictable because the ways in which environmental factors influence animal behavior are poorly understood. Gill nets and trammel nets tend to be more selective for the capture of species with external protrusions and less selective for the capture of species with compressed bodies and no protrusions.

Fish mortality when using entanglement gears is a concern. The unit of measure used to describe  $C/f$  with passive sampling gears is generally the number of animals captured per unit of time (e.g., day or hour). This is often the number of animals per net-night, the period from when a net is set in the afternoon until it is retrieved the following morning. Similar units are used with

## Trotline



## Longline



**Figure 6.4** Two types of angling gear—trotline and longline (modified from Rounsefell and Everhart 1953).

entrapment gears. Biologists sometimes resort to shorter net sets of a few hours to reduce fish mortality. In these cases,  $C/f$  is expressed as animals captured per hour.

## 6.2 ENTANGLEMENT GEARS

### 6.2.1 Gill Nets

Gill nets are horizontal panels of netting normally set in a straight line (Figure 6.1). Fish may be caught by gill nets in three ways: (1) wedged—held by the mesh around the body; (2) gilled—held by mesh slipping behind the opercula; or (3) tangled—held by teeth, spines, maxillaries, or other protrusions without the body penetrating the mesh. Fish are often retained by a combination of the capture modes.

#### 6.2.1.1 Construction

A horizontal gill net is made of a single wall of webbing attached to float and lead lines that allow the webbing to suspend in the water column. The hanging ratio, which is the length of the

### Box 6.1 Comparison of Catches with Different Passive Gears

The Nebraska Game and Parks Commission uses a standardized sampling program for monitoring fish populations. This standard program facilitates data interpretation, especially for trends through time. During autumn, experimental gill nets are used to sample walleye and trap nets are used to sample crappies. Below is a summary of catches from Sherman Reservoir, Nebraska, with gill nets and trap nets.

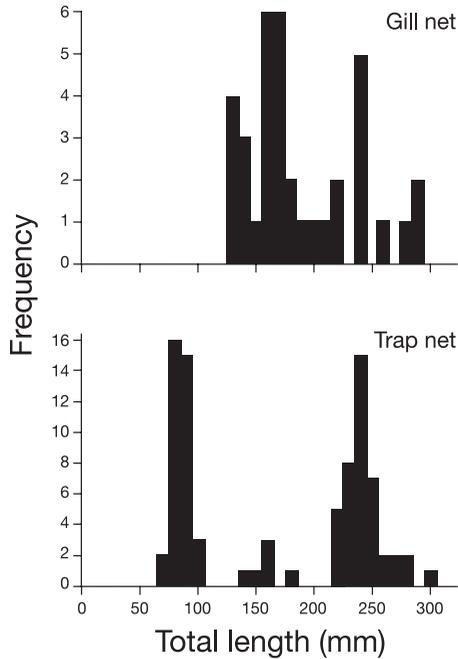
**Table** Sample size ( $N$ ), size range (minimum and maximum total length [TL]), and catch per unit effort ( $C/f$ , mean  $\pm$  SE) of fishes captured from Sherman Reservoir, Sherman County, Nebraska, with gill nets and trap nets set during autumn 2005. Effort for each gear was four net-nights (i.e., four nets set over one night).

Species	Gill net			Trap net		
	$N$	Size range	$C/f$	$N$	Size range	$C/f$
Gizzard shad	47	125–455	11.8 $\pm$ 3.9	2	105–155	0.5 $\pm$ 0.3
Common carp	5	545–635	1.3 $\pm$ 0.6	0		
River carpsucker	14	425–595	3.5 $\pm$ 1.4	0		
Shorthead redhorse	6	305–385	1.5 $\pm$ 0.3	0		
Channel catfish	33	245–875	8.3 $\pm$ 3.1	0		
Northern pike	10	601–715	2.5 $\pm$ 1.5	2	790–830	0.5 $\pm$ 0.3
White bass	20	262–373	5.0 $\pm$ 1.2	51	95–205	12.8 $\pm$ 8.7
Orangespotted sunfish	0			12	75–95	3.0 $\pm$ 1.7
Bluegill	0			118	85–185	29.5 $\pm$ 17.8
White crappie	36	135–295	9.0 $\pm$ 4.1	84	75–300	21.0 $\pm$ 4.7
Black crappie	11	125–205	2.8 $\pm$ 0.9	62	75–243	15.5 $\pm$ 5.1
Yellow perch	1	170–170	0.3 $\pm$ 0.3	4	155–165	1.0 $\pm$ 0.7
Walleye	106	199–721	26.5 $\pm$ 3.8	3	165–185	0.75 $\pm$ 0.48
Freshwater drum	113	145–325	28.3 $\pm$ 3.1	0		

Experimental gill nets captured 12 fish species, whereas the trap nets captured 9 species; only 7 species were captured with both gears. It is evident that walleye and freshwater drum were more vulnerable to capture with gill nets than with trap nets. Conversely, bluegill, white crappie, and black crappie were more vulnerable to capture with trap nets than with gill nets. Thus, conclusions drawn about a fish assemblage would be different depending on the sampling gear used.

Similarly, conclusions drawn from a population assessment would be different depending on the sampling gear used. Below are length-frequency histograms of white crappie captured with gill nets and trap nets.

(Box continues)

**Box 6.1 Continued**

**Figure** Frequency of white crappies captured per centimeter-length-group from Sherman Reservoir, Sherman County, Nebraska, with gill nets and trap nets set during autumn 2005.

Small (<130 mm TL) white crappies were captured with only trap nets. Also, with gill nets the modes of the frequency distribution of white crappies (i.e., numbers of fish caught) were centered on the 160- and 240-mm length-groups and were nearly equal, whereas these length-groups were nearly an order of magnitude different in trap nets. This suggests that the trap nets were more efficient than were the experimental gill nets at capturing white crappies less than 130 mm TL and 220–240 mm TL.

net mounted on float and lead lines divided by the length of the unmounted, fully stretched net, determines the shape of the mesh (Box 6.5; Gebhards 1966). The influence of hanging ratio is greatest on species caught by tangling. The lower the ratio, the more the diamond-shaped mesh is elongated vertically and the more efficient the gill net becomes in entangling deep-bodied fishes (Welcomme 1975).

The mesh size of gill nets is generally expressed as bar measure or stretch measure (Box 6.5). Bar measure (also known as square measure) is the distance between knots of the mesh. Stretch measure is the length of a single mesh when the mesh is stretched taut and is twice that of the bar measure. For example, a 10-cm-stretch-measure mesh is the same as a 5-cm-bar-measure mesh.

Gill-net webbing was formerly made of linen or cotton but is now mostly made of monofilament or multifilament nylon because this material catches more fish, does not deteriorate rapidly, and requires less maintenance (Lagler 1978). Monofilament nylon nets are more dif-

**Box 6.2 Gill-Net Mesh-Size Efficiency**

Efficiency of sampling gears is a primary concern for fisheries biologists. This hypothetical example illustrates the difference in efficiency of two gill-net mesh sizes. Assume that two monofilament gill nets were each 20 m long and 2 m high. Net A had mesh that was 10.5 mm (bar measure) and was appropriate (i.e., selective) for capturing brown trout that were about 90 mm TL. Net B had mesh that was 24 mm (bar measure) and was appropriate for capturing brown trout that were about 210 mm TL. We stocked two identical 1-ha hatchery ponds with brown trout. In pond X, we stocked 100 brown trout that were 85 to 95 mm TL; in pond Y, we stocked 100 brown trout that were 205 to 215 mm TL. The following day, we set net A in pond X and net B in pond Y. Both nets were set in the same area of each pond with the same orientation; that is, the two nets were fished in an identical manner. After 3 h, both nets were retrieved, and we captured 12 brown trout in net A (pond X). How many brown trout were captured in net B (pond Y)? Why did you make that prediction?

The number of brown trout captured in net B would actually be greater than the catch in net A (i.e., there should be more fish wedged in net B than in net A) because the efficiency of gill nets increases with increasing mesh size. Gill-net efficiency for brown trout was twice as great with 24-mm mesh as with 10.5-mm mesh (Jensen 1995). Thus, the number of brown trout captured in net B should have been about 24. Scientists have speculated several causes for this difference in mesh-size efficiency. Nets with larger meshes have less material, which may make it more difficult for fish to detect the net. However, the likely cause for this difference in efficiency is the different behavior of small and large fish. Larger fish tend to move greater distances, thereby increasing the odds that a given individual will encounter a net. Larger fish also tend to swim faster, thereby increasing the likelihood that a given individual will be entangled upon encountering a net.

difficult to repair and to handle in cold weather than are nets of other materials, but they are less visible to fish, easier to clean, and more durable. Both the material and the twine diameter of webbing can influence  $C/f$  because of differences in visibility, stiffness, elasticity, smell, and breaking strength (Welcomme 1975; Jester 1977).

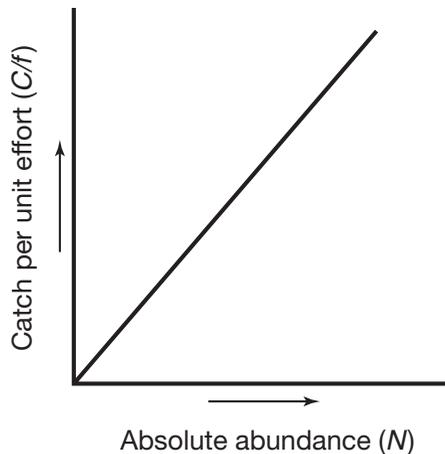
Traditionally, wooden, cork, aluminum, or plastic floats were strung on the top line to float gill nets. Lead weights were strung or crimped onto the bottom line to weight the net. Both floats and leads tend to tangle with the meshes and catch on obstructions. Consequently, foam-core float lines and lead-core lead lines have become popular.

Experimental gill nets consist of several panels of different mesh sizes to reduce the overall effects of size selectivity (Lagler 1978; Lott and Willis 1991; Hubert and O'Shea 1992; Grant et al. 2004; Rhea et al. 2005). A common design for an experimental net historically used on lakes and reservoirs is a 2-m net depth (height) and 8-m-long (wide) panels of 19-, 25-, 38-, 51-, and 64-mm-bar-mesh webbing ordered from smallest (set closest to shore for sets perpendicular to shoreline) to largest. Regier and Robson (1966) suggested that for general sampling purposes it would be more efficient for mesh sizes to increase in a geometric progression rather than the usual arithmetic progression. Most experimental gill nets are hung with a ratio of 0.5 (Box 6.5), which results in mesh diamonds

### Box 6.3 Catch per Unit Effort

When numerical abundance of fish in a stock cannot be estimated, fisheries scientists often use  $C/f$  data to make judgments about the relative abundance of fish (Hubert and Fabrizio 2007). Applications of  $C/f$  in fisheries assessments include (1) monitoring of stock abundance over time; (2) evaluation of spatial distribution patterns within stocks; and (3) assessment of stocks relative to other stocks.

A  $C/f$  index is defined as  $C/f = qN$ , where  $C$  is the number of fish caught,  $f$  is the unit of effort expended,  $q$  is the catchability coefficient or probability of catching an individual fish in one unit of effort, and  $N$  is the absolute abundance of fish in the stock. This relationship is illustrated in the figure below.



**Figure** Relationship of  $C/f$  to absolute fish abundance.

The primary assumption when using  $C/f$  as an index of relative abundance is that the number of fish captured is proportional to the amount of effort expended. As the stock declines in abundance, the number of animals captured by one unit of effort also declines. Additional assumptions include (1) the population is in equilibrium (i.e., birth, recruitment, and immigration rates are balanced by deaths and emigration rates); (2) units of effort (such as individual net or trap sets) operate independently such that one unit of fishing gear does not interfere with others; (3) the catchability coefficient ( $q$ ) is constant throughout sampling; and (4) every individual in the population has the same probability of capture (Seber 1982).

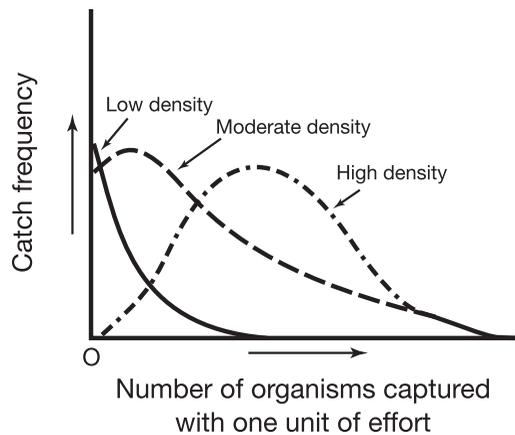
When applying  $C/f$  to assess fish stocks, attention must be given to maintaining comparable fishing effort. This is achieved by standardizing gear, methods for setting gear, time of sampling, and sampling locations. When passive gears are fished in a similar manner and time each year, they may provide reasonable estimates of the abundance of fish in a stock or allow comparisons of abundance among stocks. For this reason, most agencies and researchers adhere to strict sampling regimes within specific habitats and time periods.

*(Box continues)*

### Box 6.3 Continued

However, changes in fish behavior often lead to large variability in  $C/f$  that affects the ability of fisheries scientists to interpret temporal trends or make comparisons. Within an individual population of fishes, there may be variation in fish activity and capture vulnerability caused by water temperatures, dissolved oxygen levels, diurnal behavior patterns, spawning activities, ontogenetic changes in habitat use, or prey availability. Additionally, there may be variation in spatial distribution patterns of fish in a population caused by changes in habitat availability and other environmental factors. Because of this variability in catch rates, extensive sampling (i.e., large numbers of net sets) is often necessary to obtain sound estimates of  $C/f$ . Consequently, practitioners often apply stratified and fixed-site sampling designs that minimize variability in  $C/f$  associated with fish behavior and environmental factors (Hubert and Fabrizio 2007).

A common approach to analysis of  $C/f$  data has been to compute means and assume a normal distribution. However, analyses of  $C/f$  data are often confounded by catch frequency distributions that are not normally distributed. Distributions may approximate normality when fish populations being sampled are at high densities, but they become highly skewed at low densities.

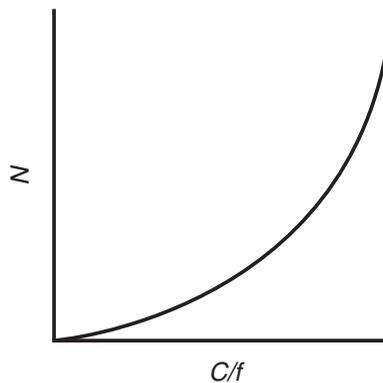


**Figure** Distribution of catch frequency per unit effort at three different population densities.

As a result, descriptive statistics derived from normal distributions (i.e., mean, SD, and 95% confidence interval) can be misleading when applied to  $C/f$  data. Additionally, because catch frequency distributions occur in many different shapes, no single data transformation (such as  $\log_{10}[x + 1]$ ) can be applied to create more normal distributions. Testing hypotheses regarding  $C/f$  generally involve application of statistical tests that assume normal distributions and the standard deviation is independent of the mean. Application of statistical analyses with these assumptions can lead to reductions in power and misleading results when assumptions are not met. Numerous alternatives exist when approaching the analysis of  $C/f$  data (Hubert and Fabrizio 2007), and practicing management and research biologists are advised to seek the advice of statisticians when designing studies and initiating data analyses.

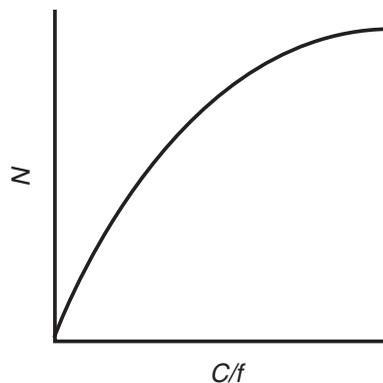
**Box 6.4 Systematic Violations of Assumption That Catch per Unit Effort Is Proportional to Density of Fish in a Population**

The assumption that  $C/f$  is directly proportional to density of fish in a population is not achieved in many situations. In some cases, fish increase their spatial distribution and spread out into adjacent nonsampled areas as abundance increases, resulting in little change in  $C/f$  and a curvilinear relationship between absolute abundance ( $N$ ) and  $C/f$ . This situation may occur with introduced or invading fish populations as they spread through a large lake or river system.



**Figure** Curvilinear relationship between absolute abundance ( $N$ ) and  $C/f$  reflecting dispersion of fish as abundance increases.

In other cases, “hyperdepletion” may occur when the most vulnerable fish are captured first, leaving behind less vulnerable individuals (Hilborn and Walters 1992; Hubert and Fabrizio 2007). In this situation, the rate of change for  $C/f$  is higher than for absolute abundance, resulting in the opposite curvilinear relationship.

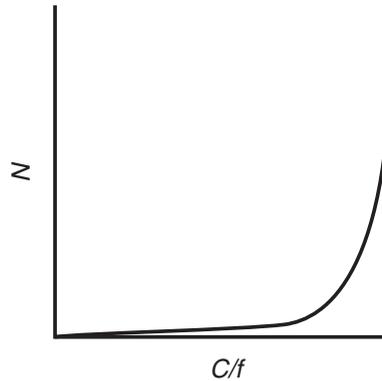


**Figure** Curvilinear relationship between absolute abundance ( $N$ ) and  $C/f$  reflecting hyperdepletion of the most vulnerable individuals.

*(Box continues)*

**Box 6.4 Continued**

In another set of cases known as “hyperstability,”  $C/f$  remains constant as absolute abundance decreases (Hilborn and Walters 1992; Hubert and Fabrizio 2007). This relationship may occur when the search for fish is highly efficient, effort is concentrated in areas with high densities of fish, and the fish remain concentrated as abundance declines. This relationship has been described among commercial (Rose and Kulka 1999) and recreational (Peterman and Steer 1981) fisheries.



**Figure** Relationship between absolute abundance ( $N$ ) and  $C/f$  reflecting concentrated distribution of fish even as abundance declines.

that are somewhat elongated in the vertical dimension. However, the effectiveness of the mesh shape varies with the morphology of the fish species being sought (Welcomme 1975).

Fisheries scientists in North America have recommended specifications for a standard sinking gill net for sampling freshwater fishes in both standing waters and rivers (Bonar et al. 2009). The standard gill net has eight panes ( $3.1 \times 1.8$  m) with meshes of 38-, 57-, 25-, 44-, 19-, 64-, 32-, and 51-mm-bar-mesh (a quasi-random order), each with a hanging ratio of 0.5. Additional add-on panels with larger mesh sizes are suggested to sample larger fishes.

#### 6.2.1.2 Deployment and Applications

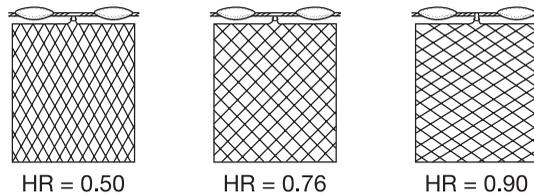
Gill nets can be set in many ways, depending on the species sought and the habitats involved (von Brandt 1964; Nedelec 1975; Beauchamp et al. 2009; Lester et al. 2009; Miranda and Boxrucker 2009; Pope et al. 2009). The most common deployment is the stationary bottom set: the net is stretched and anchored at both ends (Figure 6.1). Before it is set, the net is rigged with appropriate anchors, lines, and buoys. To set the net from a small boat, the net's anchor is dropped over the bow, and the boat is backed as the net is set. Gill nets may be set by two people, one handling the float line and the other shaking out tangles in the mesh. Gill nets may also be set by one person who handles both the float and lead lines. When larger boats are used, gill nets are usually set from the stern by means of rollers or spreaders (Gordon 1968). Nets set perpendicular to the wind in water less than 5 m deep tend to roll and tangle because of wave action (Scidmore 1970) and may have a pronounced bow to them that may reduce efficiency. Rope can be strung

### Box 6.5 Effect of Hanging Ratio on Gill Nets and Nomenclature for Measurement of Mesh Size

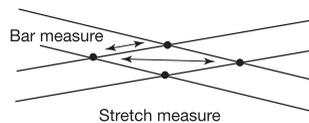
Two features of gill nets that often cause confusion among fisheries scientists are hanging ratio and the two commonly used measures of mesh size. Hanging ratio is a measure of how tightly the netting is stretched along the float line and the lead line. It is the length of the finished net divided by the length of the original netting. For example, if a 50-m-long gill net was made using 100 m of stretched mesh netting, the hanging ratio would be  $50/100 = 0.50$ . Hanging ratio is generally expressed as a decimal fraction but sometimes as a ratio (e.g., 1:2). Theoretically, the hanging ratio may range from 0 (i.e., all mesh mounted at the same point on the float line and the lead line) to 1 (i.e., the netting fully stretched out so there is no height to the net). The shape of the mesh openings is a function of hanging ratio (see figure below) and can influence species selectivity (Gabriel and von Brandt 2005). Low hanging ratios may be selective for deep-bodied narrow fishes such as crappies, whereas high hanging ratios may be selective for wide-bodied fish such as flathead catfish.

The two different measures commonly used to describe mesh size are bar mesh and stretch mesh (see figure below). Bar mesh is the length of twine between knots. Stretch mesh is the greatest distance between knots when the netting is fully stretched. Bar mesh is half of stretch mesh. For example, netting that is 50-mm bar mesh is 100-mm stretch mesh. It is important to identify clearly which measure is used when describing gill nets.

#### A. Hanging ratio = HR



#### B. Bar and stretch measures



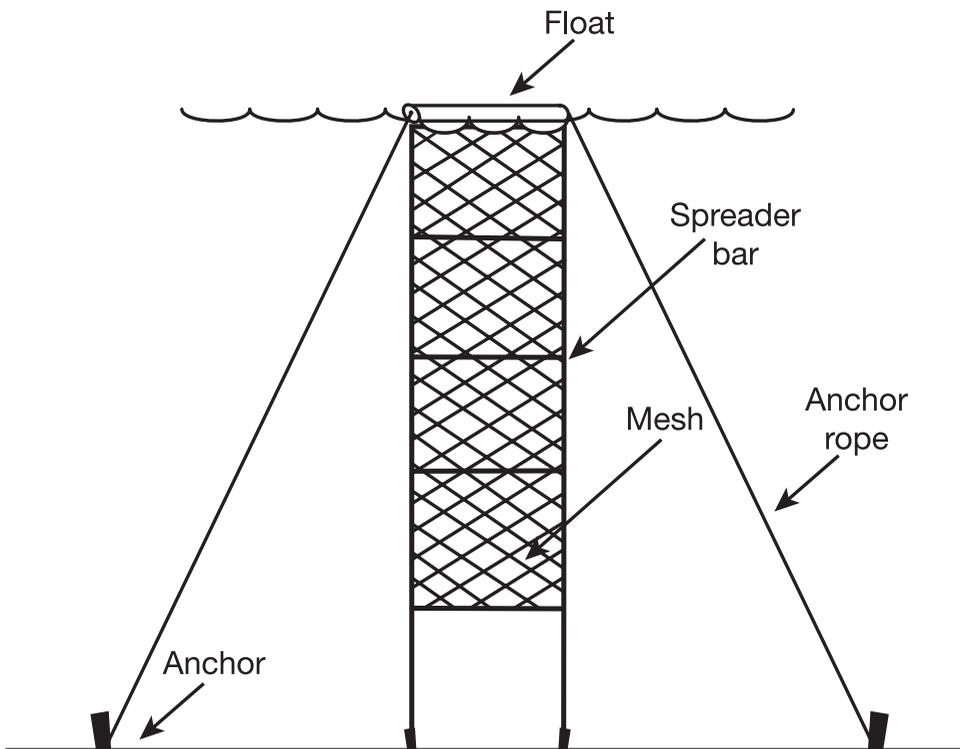
**Figure** Illustration of hanging ratio and measurements of mesh size.

under ice to facilitate the setting of gill nets or other sampling gear during winter (Hamley 1980; Hubert 1996).

Gill nets are retrieved by starting at the downwind end and pulling the net over the side or bow of the boat. When lifting long gill nets from deep water (>20 m), variable-speed, hydraulic gill-net lifters frequently are used (Gordon 1968). A gill-net lifter is a mechanical device with a rotating drum that opens and closes a set of teeth which grabs and releases the lead and float lines.

As the drum turns, it pulls the gill net into the boat over a roller mounted on the gunwale, usually at the vessel's bow. As the net is released from the roller, it passes over a "picking" table where fish are removed manually. The empty net is cleared of debris and placed in a net box or similar container in coils or figure eights. Fish are generally removed from gill nets during retrieval, but some people prefer to haul in the entire net and move to a sheltered area to remove fish. Removal of fish can be facilitated by use of a hook (known as a fish pick) to lift meshes over the opercula and slide them off the body. Fish picks are available from commercial vendors or are easily manufactured, especially by modifying screwdrivers or awls.

Depth distributions of fishes can be assessed by placing gill nets at discrete depths (Beauchamp et al. 2009). Gill nets can be suspended at various depths on drop lines from large buoys, or a buoyant net can be held below the surface by lines attached to anchors (von Brandt 1964). Beauchamp et al. (2009) recommended suspended horizontal gill nets as a standard method for sampling large coldwater lakes and reservoirs. Gill nets can be set vertically in the water column to determine the depth distribution of fishes in water up to 50 m deep. A variety of methods have been used to deploy vertical sets, but they generally involve a mechanism similar to a rolling window shade (Figure 6.5). Nets are wound around a horizontal cylinder that may also serve as a float and unwound to the bottom or to the hypolimnion; spaced, lightweight "spreader bars" hold the net open (Kohler et al. 1979; Negus 1982; Chadwick et al. 1987; Lynch et al. 1989). Gill nets also can be floated at the surface of lakes (Rhea et al. 2005). Lester et al. (2009) recommended use of very tall nets (i.e., 6 m) floated at the surface as a standard method for sampling small coldwater lakes and reservoirs.



**Figure 6.5** A vertically set gill net with float, net, and spreader bars.

Gill nets can be fished by setting them around concentrations of fish or areas suspected of harboring fish. After the net is set, fish can be driven into it with noise, light, electricity, or chemicals. White (1959) described several encircling net sets made by commercial fishers in the Tennessee River. Similar methods have been used to capture mullets in coastal areas.

Gill nets sample fishes in a wide variety of habitats (Bonar et al. 2009). Bottom sets can be made at depths greater than 100 m. The use of gill nets is generally limited to areas free of obstructions, snags, and floating debris, as well as locations with little or no current. Although gill nets are not considered to be widely applicable in riverine habitats, they have been drifted in the current, set in eddies, used as seines, and anchored at the downstream end of sandbars or bridge abutments, where they were allowed to swing in the current (Schwanke and Hubert 2004; Argent and Kimmel 2005; Kennedy et al. 2007). Curry et al. (2009) recommended use of bottom set gill nets as a standard method for sampling coldwater rivers. Gill nets are widely used to monitor populations and determine distributions of fishes in lakes and reservoirs (Fisheries Techniques Standardization Committee 1992; Hubert and O'Shea 1992; Bonar et al. 2009). They are commonly used in remote areas where access can be attained only by aircraft, boat, horse, or hiking. Long gill nets are used in inland and marine commercial fisheries. Anchored or set gill nets are used to harvest a variety of fishes from freshwater lakes (Hansen et al. 1996; Sullivan 2003), large rivers (Almeida et al. 2003), and marine systems (Vestergaard et al. 2003; Revill et al. 2007). Drifted gill nets are used principally for pelagic ocean species such as herrings and salmon (Rounsefell and Everhart 1953; Springborn et al. 1998).

Gill nets are routinely used in monitoring programs, and standard methods have been recommended for many types of waters (Bonar et al. 2009). The *C<sub>f</sub>* of fish in gill nets has been related to estimates of several factors of interest to managers, such as recruitment (Willis 1987; Richards et al. 2004; Bunnell et al. 2006; Quist 2007), harvest (Nesler 1986), angler catch rates (Isbell and Rawson 1989), fish density (Bulkley 1970; Borgstrom 1992; Pierce et al. 2006; Bronte et al. 2007), and length structure of fish in a population (Wilberg et al. 2003, 2005; Pierce et al. 2006). Fish sampled with gill nets are generally not used for food habit studies because of the proclivity of fish captured in gill nets to regurgitate their stomach contents (Sutton et al. 2004).

Gill nets are less appropriate when live fish must be obtained and released because many fish caught by gill nets die in the net or are injured upon removal, although selecting appropriate twines, setting nets for short durations (e.g., 2 h instead of 24 h) and sampling when waters are cold can reduce mortality (Lester et al. 2009). Gill nets stress fish more than do other types of passive gear (Hopkins and Cech 1992). A major disadvantage of gill nets for population assessment is the capture of nontarget fishes (i.e., bycatch) and frequent high mortality thereof.

#### 6.2.1.3 Target Organisms

Gill nets are especially effective in the capture of fish species that are active or move substantial distances during their daily routines. Freshwater fishes in the families Acipenseridae, Clupeidae, Ictaluridae, Esocidae, Salmonidae, and Percidae are particularly vulnerable to capture with gill nets. Species selectivity has been determined using experimental (Berst 1961; Heard 1962; Trent and Pristas 1977; Yeh 1977; Boxrucker and Ploskey 1989) and commercial gill nets (Bronte and Johnson 1983, 1984).

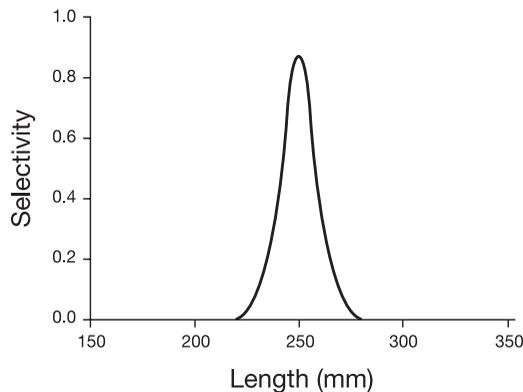
#### 6.2.1.4 Biases

The size selectivity of various mesh sizes is quite specific with gill nets (Box 6.6). For a particular mesh size, fish of a particular size are held most securely; smaller or larger fish are less likely

### Box 6.6 Gill-Net Selectivity

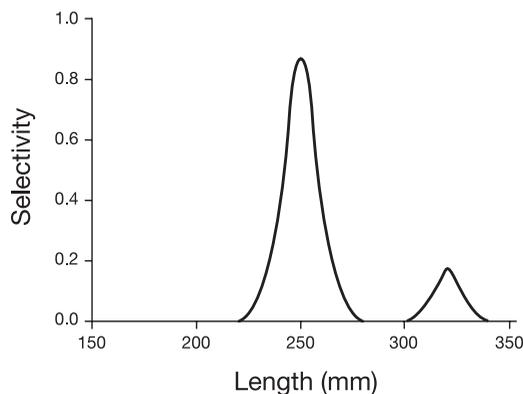
Gill nets are highly selective over a narrow size range of fish for each mesh fished (Hamley and Regier 1973; Hamley 1975; Hansen et al. 1997; Anderson 1998). Thus, commercial fishers can precisely predict the size of fish they will bring to market based on the mesh size they are fishing and the characteristics of the target species. Similarly, assessment biologists can adequately sample the vast majority of the population by choosing an appropriate range of mesh sizes to target most fish sizes in a given population.

The pattern of size selectivity by gill nets typically follows the shape of a bell curve with a high but narrow peak around the fish size most efficiently collected.



**Figure** Typical pattern of fish size selectivity by gill net.

Sometimes, a bimodal distribution occurs. This frequently happens when the greatest selection reflects those fish that are caught by wedging or gilling and a secondary peak includes larger fish caught by tangling.

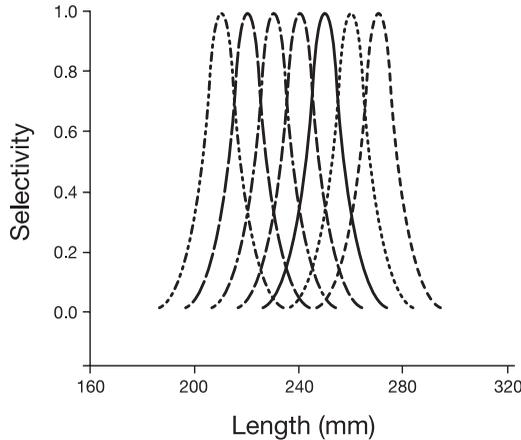


**Figure** Bimodal pattern of fish size selectivity caused by secondary tangling by gill net of larger fish.

*(Box continues)*

**Box 6.6 Continued**

Experimental, or graded-mesh, gill nets can provide almost complete coverage of the entire size range of the adult population because of overlapping selectivity curves.



**Figure** Overlapping fish selectivity curves obtained with experimental gill nets.

to be caught. Very small fish can swim through the mesh, and very large fish cannot penetrate into the mesh to become entangled. A typical gill-net size-selectivity curve is bell shaped; catch frequency declines to zero at both sides of a maximum (Pope et al. 1975). Size-selectivity curves for various mesh sizes have been computed for many species (Hamley 1975; Jensen 1986, 1990; Reddin 1986; Winters and Wheeler 1990; Henderson and Wong 1991; Lott and Willis 1991; Wilde 1993; Hansen et al. 1997). Two generalizations regarding size selectivity are (1) the optimum girth for capture is about 1.25 times the mesh perimeter and (2) fish more than 20% longer or shorter than the optimum length are seldom caught (Hamley 1980). Substantial variation in the shape and magnitude of size selectivity curves has been observed. For example, Hamley and Regier (1973) described a bimodal curve for walleye because fish too large to be captured within the mesh were entangled by their teeth or spines. The shape of curves can vary within a species by sex and season (Hamley 1975).

Frequently, though not always, multi-mesh gill nets overestimate size structure (e.g., proportional size distribution; Willis et al. 1985) and age structure of fish populations because efficiency increases with mesh size (Box 6.2). Estimates of growth rate, mortality, and body condition can also be biased because larger fish of each age-group are more efficiently captured (Hamley 1980). Methods have been developed to correct for the size selectivity of an array of mesh sizes when the size distribution of fish in a stock is being described (Willis et al. 1985; Spangler and Collins 1992).

In general, large fish are more easily captured than are small fish when using gill nets. Young fish are not the most abundant age-group in most samples collected with experimental gill nets because small fish either are not as likely to push themselves into the mesh or have a tendency to detect the net and avoid capture. However, very small mesh gill nets (6- to 10-mm

bar mesh) can be used effectively to sample some age-0 fishes (Janssen and Luebke 2004). The most important factors influencing the size selectivity of a single-mesh gill net for a particular species are mesh size, hanging ratio, and characteristics of the twine such as elasticity, diameter, visibility, strength, and flexibility (Jester 1973, 1977), as well as time and manner in which the net is fished.

Mesh material can substantially influence gill-net efficiency. In general, nylon twine yields a greater  $C/f$  than does linen or cotton, and monofilament nylon twine yields the greatest  $C/f$  of all materials (McCombie and Fry 1960; Berst 1961; Larkins 1963; Pristas and Trent 1977; Collins 1979; Henderson and Nepsey 1992). Most biologists now use monofilament nylon gill nets because of their superior efficiency over multifilament gill nets. However, changes in mesh material have confounded long-term monitoring programs by altering the efficiency of the gear (Maki et al. 2006) and are therefore infrequent in ongoing assessment programs.

Species and size selectivity of gill nets, as well as efficiency for particular species, are governed to a great degree by the construction of a net. For example, both mesh size and net length affected the species captured with gill nets in large rivers (Argent and Kimmel 2005). Monitoring or assessment projects should use gill nets of identical design, material, and construction over the course of the project. Lack of concern for variables seemingly insignificant, such as diameter (Hansen 1974) or color of the twine (Jester 1973), can influence  $C/f$  and size selectivity and therefore the quality and comparability of the data.

The capture of fish in gill nets is also a function of fish activity. The activity of many fishes is related to the amount of light under water, which leads to diurnal movement patterns. Most species exhibit nocturnal or crepuscular activity peaks that are consistent from day to day within a particular season. Seasonal patterns in movements and distributions can occur as a result of spawning activity, habitat requirements, food availability, and water temperature (Hubert and O'Shea 1992; Grant et al. 2004; Creque et al. 2006). Physical and chemical variables such as weather fronts, currents, water temperatures, water depths, water-level fluctuations, turbidity, and thermocline location influence fish movements and distributions (Berst 1961; Welcomme 1975; May et al. 1976; Pristas and Trent 1977; Craig and Fletcher 1982; Hubert and Sandheinrich 1983; Craig et al. 1986; Mero and Willis 1992; Pope and Willis 1996). Many of these variables can be measured, allowing predictive relations between factors influencing fish activity and subsequent gill-net catches to be defined.

The duration of a gill-net set also influences sampling results. Catches do not accumulate in a gill net at a uniform rate (Kennedy 1951; Austin 1977; Minns and Hurley 1988; Rotherham et al. 2006), and efficiency decreases as fish accumulate (Hansen et al. 1998). Eventually, the number of captured fish can reach a saturation point after which additional capture of fish does not occur. Catch is generally not linearly related to the duration of the set or "soak time," and saturation generally occurs when only a small proportion of the meshes are occupied.

Sampling regime (i.e., season, time of day, location, and duration of sets) influences  $C/f$ . A standardized sampling scheme can be used from year to year, as well as among water bodies, to minimize the variability that is generated by physical, chemical, and biological variables (Bonar et al. 2009). A rigidly defined sampling design that identifies the season, time, location, and duration of sets, coupled with precise gear and deployment specifications, can reduce much of the variability among gill-net samples and enable comparisons of  $C/f$  over time or among water bodies (Hubert and O'Shea 1992; Mero and Willis 1992; Hansen 1996; Schneeberger et al. 1998; Grant et al. 2004; Wilberg et al. 2005; Pierce et al. 2006).

## 6.2.2 Trammel Nets

A trammel net generally consists of three parallel panels of netting suspended from a float line and attached to a lead line (Figure 6.1). The two outer panels are of large-mesh netting, whereas the inner panel is of small mesh. The small-mesh inner panel has greater depth and hangs loosely between the two outer panels. Fish pass through one of the large-mesh outer panels, hit the small-mesh inner panel, and push the small-mesh panel through one of the openings of the facing large-mesh outer panel. This action, combined with the movement of the fish, forms a bag or pocket in which the fish is entangled. Small fish may be wedged or gilled, whereas large fish may be tangled in the netting.

### 6.2.2.1 Construction

Trammel nets generally are constructed of cotton or nylon webbing because these materials are highly flexible. Numerous designs of trammel nets have been used by commercial fishers (Dumont and Sundstrom 1961; Nedelec 1975). A typical trammel net used in reservoirs or rivers is 2 m deep with 250-mm-bar-mesh outer panels and a 25-mm-bar-mesh inner panel. The inner panel typically is two-thirds greater in depth (i.e., 3.3 m deep). Both monofilament and multifilament trammel nets have been used. Monofilament mesh on the inner panel has improved catch rates by an average of 1.85 times over multifilament material, but catch rates were similar between nets with monofilament and multifilament mesh in the outer panels (Balik and Cubuk 2000). The improved efficiency probably was caused by reduced visibility of monofilament relative to multifilament mesh.

### 6.2.2.2 Deployment and Applications

Trammel nets are set in the same ways as gill nets (i.e., stationary bottom sets or drifting, floating, or encircling sets). Commercial fishers consider trammel nets to be most efficient when the nets are set around an aggregation and the fish are frightened or driven into the nets (Starratt and Barnickol 1955; White 1959). A typical set of this type involves surrounding an area of aquatic vegetation with trammel nets. Stationary bottom sets can be made in lakes, backwaters, or slow-moving sections of rivers. Drifted trammel nets have been used to sample channels of large rivers that are free of snags (Hubert and Schmitt 1982a; Hurley et al. 1987).

Despite their versatility, trammel nets have not been widely used in population assessments. However, trammel nets were effective in monitoring trends in abundance of humpback chub in the Little Colorado River (Coggins et al. 2006). A standard drifting trammel net has been described for sampling fishes in warmwater rivers of North America (Guy et al. 2009). Both multi-mesh gill nets and trammel nets caught similar numbers and sizes of fishes in an Australian estuary, but the gill net required less effort to deploy and retrieve and provided greater precision of  $C/f$  (Gray et al. 2005). However, the  $C/f$  of commercial species in trammel nets can provide a reliable estimate of total harvest from a water body (Bronte and Johnson 1984). Furthermore, trammel nets are used to sample fish assemblages in a variety of marine and estuarine habitats, such as around gas platforms (Fabi et al. 2002b) and in small marine reserves (Collins et al. 2002).

### 6.2.2.3 Target Organisms

Trammel nets are selective for large, mobile species that occur in shallow water of lakes and reservoirs (Bronte and Johnson 1983, 1984; Paukert 2004). Trammel nets also effectively capture large fishes in channels of large rivers when the nets are drifted with the current (Guy et al. 2009). For example, buffaloes and common carp constituted more than 95% of the trammel

net catch at two locations on the Mississippi River (Starrett and Barnickol 1955). Additional taxa that have been targeted with trammel nets include sturgeons, suckers, burbot, and freshwater drum. Trammel nets are sometimes used as a sampling gear because there is less mortality associated with them than with gill nets. However, the time required to remove fish from trammel nets is often much more than the time needed to remove fish from gill nets.

#### 6.2.2.4 Biases

The sampling biases that exist with gill nets also occur with trammel nets; however, trammel nets are less size selective than are gill nets because a higher proportion of fish are captured by tangling (Fabi et al. 2002a). Observed mortality of fish captured in trammel nets is less than that in gill nets. The low mortality of both targeted and untargeted fishes (i.e., the bycatch) can make trammel nets a desirable gear for fish population sampling and assessment.

### 6.3 ENTRAPMENT GEARS

Animals enter entrapment gear by their own movements. They are captured when the entrance to the gear is in the path of their movement, when they attempt to move around or over a barrier, or when they are attracted to the enclosure by the presence of bait, other animals, or the cover it appears to provide. After entry, an animal may escape through an entryway or be retained until it is removed. Entrapment gears are designed to take advantage of migration, cover-seeking habits, escape reactions, or diets of aquatic animals (Dumont and Sundstrom 1961; von Brandt 1964; Nedelec 1975; Everhart and Youngs 1981; Hart and Reynolds 2002). Entrapment gears used in fisheries science are often small, portable versions of commercial fishing gear.

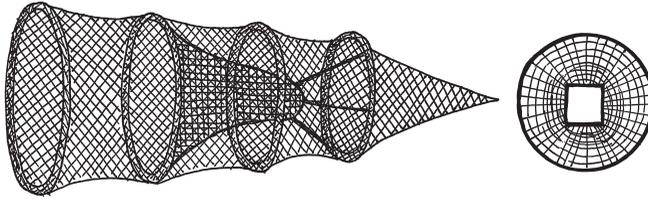
#### 6.3.1 Hoop Nets

A hoop net is a cylindrical or conical net distended by a series of hoops or frames covered by web netting. The net has one or more internal funnel-shaped throats directed inward from the mouth of the net (Figure 6.2; Nedelec 1975). Local terminology for hoop nets can be confusing because the name often refers to the targeted species associated with a particular design. Some names given to hoop nets include catfish nets, buffalo nets, bait nets, fiddler nets, and even fyke nets (Starrett and Barnickol 1955; Guy et al. 2009).

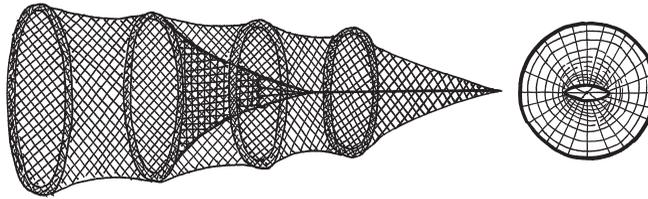
##### 6.3.1.1 Construction

Hoop nets are typically made with four to eight wooden, plastic, fiberglass, or steel hoops. Hoop diameter can vary from 0.5 m to over 3 m. The cotton or nylon webbing tied around the hoops can range from 10-mm to over 10-cm bar mesh. Generally, two funnel-shaped throats are attached, one to the second hoop and a second to the third or fourth hoop from the mouth of the net. There are two basic designs of throats, square or finger (Figure 6.6; Guy et al. 2009). A square throat is simply a square to circular opening in the constricted end of the funnel. A finger throat is composed of two half-cones of twine on each side of the hoop secured to a back hoop (Hansen 1944). A finger throat is often placed in the second funnel to lessen the chances of fish escaping after they have passed through it. The closed end of the hoop net, where the fish accumulate, is called the cod end or the pot. A drawstring is generally attached to the cod end for removing captured fish. Hoop nets can be protected from deterioration by periodic dipping in petroleum-based net-coating material.

### Square throat



### Finger throat



**Figure 6.6** Examples of a square throat and a finger throat used in hoop nets.

#### 6.3.1.2 Deployment and Applications

In rivers, hoop nets are set fully submerged with the mouth facing downstream (Figure 6.2; Guy et al. 2009). They are held in place with an anchor or stake driven into the stream bottom and a rope attached to the cod end. Metal stakes 5–15 mm in diameter and 0.6–1.5 m in length can be driven into the stream bottom in water up to 5 m deep by means of a driver pole. A driver pole is a long pole with a sleeve (2–4 cm diameter) at one end. A rope should be attached to the stake before it is driven into the stream bottom. Water current keeps the hoops separated and the net stretched. If the current is not sufficient to stretch a hoop net, the net can be stretched out and held in place with ropes and stakes. During some months, hoop nets may be baited with cheese scraps, processed soybean or cottonseed cake, or frozen fish to enhance their efficiency for catfishes and buffaloes (Carter 1954; Pierce et al. 1981; Gerhardt and Hubert 1989; Flammang and Schultz 2007). Hoop nets most often are used in channel habitats of rivers because they can be set and fished effectively in strong currents without being washed away or becoming clogged with debris. They have been used to assess population density (Coggin et al. 2006) and population structure (Gerhardt and Hubert 1991), evaluate life histories (Smith and Hubert 1989; Hubert and O’Shea 1991), and describe habitat associations (Hubert and Schmitt 1982b) of fishes.

Commercial fishers generally set hoop nets without buoys to protect their gear from vandalism and theft. Landmarks are used to identify the location of set nets. Retrieval is achieved by dragging the bottom with a grappling hook until the net or rope is hooked. Fisheries biologists often attach buoys to the anchor or stake for easy retrieval of the hoop nets, and buoys are often labeled to indicate the purpose of the netting and the agency contact information.

Hoop nets can be modified for use in lakes and reservoirs. For example, a rigid hoop net effectively captured burbot in lakes (Bernard et al. 1991). Tandem hoop nets (several hoop nets attached together with a bridle placed on the mouth of one net and the cod end of the other net)

effectively captured channel catfish in reservoirs (Walker et al. 1996; Sullivan and Gale 1999; Michaletz and Sullivan 2002; Flammang and Schultz 2007).

### 6.3.1.3 Target Organisms

Hoop nets are selective for fish taxa, such as ictalurids, large cyprinids, and some centrarchids, that are attracted to cover, bait, or other fishes (Guy et al. 2009). In the Mississippi River basin, different designs of hoop nets are selective for catfishes, buffaloes, or common carp (Starrett and Barnickol 1955). Fish captured in hoop nets are generally captured unharmed and can be released with little or no injury to the fish, which is important for nontarget species. However, mortality rates are high for air-breathing animals such as reptiles, mammals, and birds that may be inadvertently captured in fully submerged hoop nets (Sullivan and Gale 1999).

### 6.3.1.4 Biases

Net construction (hoop diameter, mesh dimensions, and mouth size) has substantial influence on the species and size selectivity of hoop nets (Hubert and Schmitt 1982b; Holland and Peters 1992; Hubert and Patton 1994; Flammang and Schultz 2007). For example, nets of three mesh sizes (25-, 32-, and 38-mm bar mesh) yielded significant differences in species composition, length frequencies, and *C/f* of fishes in the Platte River, Nebraska (Holland and Peters 1992). Large-diameter hoop nets captured twice as many fish and half again as many species as small-diameter nets with equal sampling effort in the Mississippi River (Hubert and Schmitt 1982b). The species selectivity and *C/f* of hoop nets can also be influenced by bait (Pierce et al. 1981; Gerhardt and Hubert 1989; Flammang and Schultz 2007); however, the catch rate of some species may not be enhanced or may even be diminished by baiting (Stone 2005). Escape rates of different species from hoop nets also influence sampling results because some species are more adept at escape than are others (Hansen 1944).

Physical, chemical, and biological variables can have significant influences on *C/f*. Season, water temperature, current velocity, turbidity, dissolved oxygen, and habitat type all affect *C/f* of individual species (Mayhew 1973; Hubert and Schmitt 1982b; Holland and Peters 1992). Of these factors, the most influential variables seem to be season, water temperature, and turbidity. Catch rates are often greatest immediately preceding and during the spawning periods of riverine fishes (Smith and Hubert 1989; Hubert and O'Shea 1991). In most cases, *C/f* declines as water temperature declines.

As with entanglement gear, the design and construction of hoop nets can be standardized, along with sampling time and location, to reduce sampling variability. Two types of hoop nets have been recommended by fisheries scientists as standard gears for sampling warmwater fishes in rivers of North America (Guy et al. 2009). However, little can be done to control the variability of physical factors, such as turbidity and current velocity, that are associated with dynamic river systems. Some variability is to be expected when sampling complex systems.

### 6.3.2 Fyke Nets and Trap Nets

Fyke nets are similar to hoop nets but are modified for use in lentic habitats. Fyke nets have one to three leads or wings of webbing attached to the mouth to guide fish into the enclosure (Figure 6.2; Miranda and Boxrucker 2009; Pope et al. 2009). The net is set so that the leads or wings intercept moving fish. As fish follow a lead or wing in an attempt to get around the netting, they swim into the enclosure and are retained. Fyke nets are also known as wing nets, frame nets, trap nets, or hoop nets. Modified fyke nets have rectangular frames in place of the first two hoops (Figure 6.2) to enhance their stability in turbulence produced by wind (i.e., to keep the net from

rolling). Rolling twists leads and reduces capture efficiency because fish can swim under twisted leads and continue on their original path of movement.

A variety of large entrapment devices has been used in coastal-marine and large-lake fisheries (Dumont and Sundstrom 1961; Alverson 1963; Grinstead 1969). These include the pound-net fishery of the Atlantic coast (Reid 1955) and the deep-trap-net fishery of the Great Lakes (Van Oosten et al. 1946). Modified, scaled-down versions of commercial trap nets have been used by fisheries biologists (Crowe 1950; Beamish 1972; Clark et al. 2007).

#### 6.3.2.1 Construction

Fyke nets are hoop nets to which one or more leads are attached (Figure 6.2). A single lead extending from the mouth of the hoop net outward along the axis of the net can be added in lentic habitats to increase catch efficiency (Winkle et al. 1990; Hubert and Guenther 1992; Johnson et al. 1992; Clark et al. 2007). Leads are generally of the same height as the hoop net and constructed of similar net material. They are suspended between buoyant and weighted lines much like a gill net.

Modified fyke nets are widely used to sample fishes in lakes and reservoirs (Figure 6.2). They have a single lead extending outward along the axis of the net or have two wings added at an angle to the lead (often at angles of about 45° to the lead). Leads and wings are held in place with stakes or anchors. Fisheries scientists have recommended specifications for a standard fyke net for sampling warmwater fishes in standing waters of North America (Miranda and Boxrucker 2009; Pope et al. 2009).

#### 6.3.2.2 Deployment and Applications

Generally, fyke nets and trap nets are set on the bottom in shallow water not much deeper than the height of the leads, wings, and first frame or hoop, but they can be set at depths up to 15 m (Miranda and Boxrucker 2009; Pope et al. 2009). The net and lead are stretched taut and attached to anchors or stakes set into the bottom. A single-pot set involves one lead and one pot, where the end of the lead is set on or near the shore. The lead is extended perpendicular to shore to intercept fish moving parallel to the shore and so that fish cannot swim around or under it. When the net is set from a small boat, it is generally placed on the bow with the pot on the bottom and the lead on top. The end of the lead is staked or anchored and played out as the boat moves in reverse. When the lead is fully extended, the pot is put overboard, stretched, and staked or anchored in position. Fish are removed by lifting the pot into the boat, opening the drawstring on the cod end, and shaking fish out of the pot into a holding tank.

Fyke nets can also be deployed away from shore in pairs with a single lead between them (Nedelec 1975). For example, a tandem set of fyke nets consists of two fyke nets set facing each other and joined by a single lead (Poole 1990; Krueger et al. 1998). This type of set may be made parallel to shore along the outer edge of weed beds or along shallow offshore reefs. However, it can also be set perpendicular to shore so that fish moving along the shoreline and encountering the lead are likely to be captured whether they move along the lead toward shore or away from shore. These nets have also been used in estuaries with the lead set parallel to tidal currents.

Fyke nets and trap nets are generally used in shallow areas of lakes and reservoirs (Crowe 1950; Clark et al. 2007; Miranda and Boxrucker 2009; Pope et al. 2009). They have been used to sample fishes in areas of streams and rivers with slow current velocities as well as in backwaters and sloughs (Swales 1981; Jellyman and Graynoth 2005). Fyke nets can be used in relatively heavy vegetation or marsh-type habitats. Where dense submerged or emergent vegetation occurs,

paths can be cut to place fyke nets, but net damage by aquatic mammals such as muskrats can be substantial in these habitats (Kelley 1953). Fyke nets and trap nets can be used over a clean, firm bottom. They are not applicable for bottom sets on soft bottoms because anchors fail to hold.

Floating trap nets provide an alternative to bottom-set modified fyke nets (Miranda et al. 1996). A floating version of a trap net, called a Merwin trap, has been used to harvest fish commercially in Alaska, to sample salmonids in the northwestern USA, and as a means to control northern pikeminnow in the Columbia River (Lynch 1993; Salow 2005). These traps consist of a floating fyke net with floating leads extending to the shore. They are used in impoundments and stretches of rivers with very low current velocities to capture fish moving relatively close to shore.

### 6.3.2.3 Target Organisms

Fyke nets and trap nets are selective for certain species and sizes of fish (Miranda and Boxrucker 2009; Pope et al. 2009). Cover-seeking, mobile species seem to be the most susceptible to capture (Hoffman et al. 1990). Fyke nets have been used to capture freshwater eels in New Zealand rivers (Jellyman and Graynoth 2005). Modified fyke nets are especially efficient in the capture of crappies (Boxrucker and Ploskey 1989; McNerny 1989). Fyke nets and trap nets are effective in the capture of migratory species that tend to follow shorelines.

### 6.3.2.4 Biases

Fyke nets and trap nets are species (Laarman and Ryckman 1982) and size (Meyer and Merriner 1976; Naismith and Knights 1990; Milewski and Willis 1991; Kraft and Johnson 1992) selective, but they are less selective than are gill nets. They are selective for larger fish of age-groups above the minimum imposed by the physical dimensions of the netting (Latta 1959). Some selectivity also occurs because of variable escape rates relative to season, species, and size of fish (Hansen 1944; Patriarche 1968). Trap nets can be modified to allow escapement of small fishes in commercial fisheries (Meyer and Merriner 1976).

The location of fyke nets or trap nets in lakes or reservoirs, as well as the manner in which they are set, can influence catch (Bernhardt 1960). Seasonal variation in catches is typical (Hansen 1953; Kelley 1953; Guy and Willis 1991; Kubeka 1992; Cross et al. 1995; Krueger et al. 1998; Hardie et al. 2005; McNerny and Cross 2006). Standardized nets, sampling locations, and times are needed to reduce sampling variability.

Fyke nets and trap nets induce less stress on captured fish than do entanglement gears (Hopkins and Cech 1992), and most captured fish can be released unharmed. However, gilling of small fish in the mesh of fyke nets and trap nets causes some mortality (Schneeberger et al. 1982; Peck and Schorfhaar 1993). Fyke nets are widely used in the assessment of fish stocks because low mortality of fish is associated with their use, but catch rates with these nets are generally lower than those with gill nets. The *C/f* of fishes in fyke nets and trap nets has been related to the duration of sets, habitat, and season (Hamley and Howley 1985; Boxrucker and Ploskey 1989; Schultz and Haines 2005; Breen and Ruetz 2006) as well as the abundance of fish (Ryan 1984; McNerny and Cross 2006).

### 6.3.3 Pot Gears

Pot gears are portable, rigid traps with small openings through which the animals enter. They are used to capture fishes and crustaceans as well as other invertebrates. These devices vary in designs and dimensions depending on the species sought (Carter 1954; Sundstrom 1957; Beall

and Wahl 1959; Dumont and Sundstrom 1961; Alverson 1963; Nedelec 1975; Rounsefell 1975; Schwartz 1986; Perry and Williams 1987; Hi and Lodge 1990; Furevik 1994). Lobster pots, minnow traps, slat traps for catfishes, eel pots, and crab pots are examples of different types of pot gears (Figure 6.3). Pot gears are generally small enough that many of the devices can be put on a boat or carried by hand. Pot gears are most efficient in the capture of bottom-dwelling species seeking food or shelter (Everhart and Youngs 1981). To reach a receptacle containing bait, the fish or crustacean must pass through a more or less conical-shaped funnel in most pot designs. In some designs, they pass through more than one funnel, making escape more difficult.

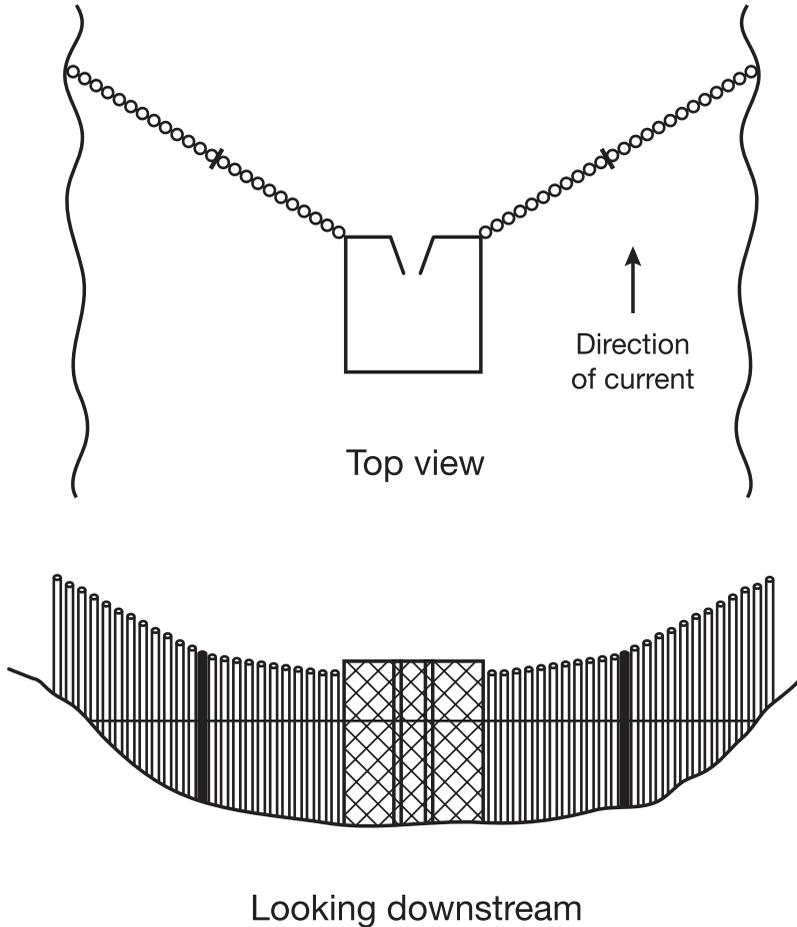
An example of a typical pot gear is the half-round lobster pot constructed with a rectangular base and three half-round bows, one at each end and one near the center (Figure 6.3; Dumont and Sundstrom 1961; Alverson 1963; Everhart and Youngs 1981). The bows are covered with lath, and a door is constructed on one side for removal of American lobsters. The pot contains two inside compartments. Lobsters enter the smaller chamber through a funnel of netting on either side of the pot. From the smaller chamber, the animal passes through another funnel that is attached to the middle bow and leads to the larger parlor. Bait is placed on a hook or in a mesh bag attached to the center bow in the parlor section. The lobster pot is weighted with bricks or stones, and a buoy line is attached to a lower corner of the pot. Commercial fishers deploy the gear from boats in strings of 10–15 pots that are spaced 10–20 m apart. The crayfish industry in North America also depends on trapping crayfish in pot gear. As a result, substantial work has gone into enhancing gear efficiency (Rach and Bills 1987; Romaine and Osorio 1989; Stuecheli 1991; Kutka et al. 1992). Similarly, channel catfish and blue catfish are commercially harvested with pot gears (Perry 1979; Perry and Williams 1987) such as slat traps (Figure 6.3).

Pot gears have been used to monitor and assess fish populations. One of the most studied pot devices is the Windermere perch trap, which targets Eurasian perch (Figure 6.3; Worthington 1950; Bagenal 1972; Lapointe et al. 2006). The trap is constructed with three semicircular wire hoops attached to a 67 × 76-cm base and covered with netting made of 1.3-cm-diameter hexagonal wire mesh. One end of the trap has a funnel with an 8.5-cm-diameter opening, and the other end has a door for removal of the catch. The traps are set unbaited. The trap is cheap, easy to make, and easy to use and has been used to estimate population age structure and body condition of Eurasian perch. It is not efficient for monitoring relative abundance because of the variability in catch among traps and sets of individual traps.

A problem associated with pot gears, but also characteristic of other passive gears, is continued capture of animals by the gear if it is lost—a process called “ghost fishing” (Guillory 1993). This can be especially problematic for pot gears because the self-baiting effect from dead fish inside the pot could result in a prolonged period of fishing (Furevik 1994). Efforts have been made to incorporate biodegradable material (Kumpf 1980) to allow escape of captured organisms from lost gear.

#### 6.3.4 Weirs

Weirs are barriers built across a stream to divert fish into a trap (Figure 6.7). They are most suited for capturing migratory fishes as they move upstream or downstream. A variety of weir designs has been used to capture fish; they can be permanent or temporary structures (von Brandt 1964; Welcomme 1975; Craig 1980). The Wolf-type weir (Wolf 1951) is an efficient design used to capture salmon and trouts moving downstream. The basic design has been applied in large salmon streams with extremely variable flow (Hunter 1954). Resistance-board weirs have been



**Figure 6.7** A portable weir and metal trap to capture upstream-migrating fishes in streams.

developed as a flood-resistant alternative to traditional weirs and are used to count adult salmon migrating in rivers (Tobin 1994; Stewart 2002). Whelan et al. (1989) described an improved design for use in rivers with severe and rapid fluctuations in flows. Salmonid smolt traps that use weirs have been designed to assess emigration in small rivers and through American beaver ponds (Tsumura and Hume 1986; Elliott 1992). The traps are relatively inexpensive, easily maintained, and effectively capture smolts. In large rivers where weirs cannot be constructed, floating inclined-plane smolt traps have been used (McMenemy and Kynard 1988; DuBois et al. 1991). Two-way fish traps have been designed for use in small trout streams (Whalls et al. 1955; Twedt and Bernard 1976). Two-way fish traps are effective in relatively constant flows without substantial amounts of debris in the water.

Weirs have been used to gather data on age structure, condition, sex ratio, spawning escapement, smolt production, abundance of sexually mature adults, and migratory patterns of fish. The use of weirs is generally restricted to small rivers and streams because of construction expense, formation of navigation obstacles, and tendency of weirs to clog with ice and debris, which can cause flooding or collapse of the structure. However, weirs are used extensively in

the St. Lawrence River and in Maine to harvest American eels commercially (McCleave 2001; Robitaille et al. 2003).

### 6.3.5 Fish Wheels

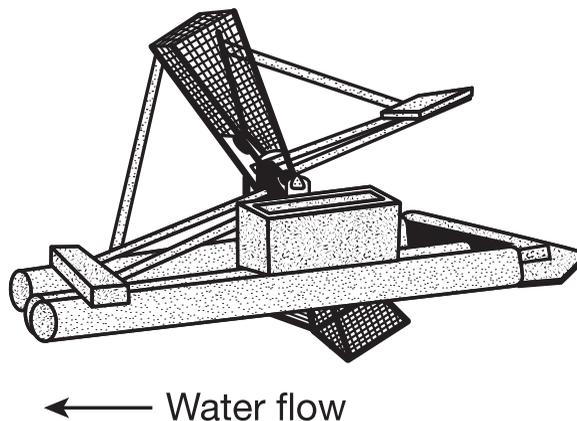
Fish wheels were developed to capture migrating fishes in rivers with substantial current (Figure 6.8). They originated in North Carolina, were used commercially in the Columbia River of Oregon and Washington before 1900 (Donaldson and Cramer 1971; Underwood et al. 2004), and were introduced to Alaska in about 1900. Meehan (1961) suggested that fish wheels may be applicable as sampling tools for research and management of Pacific salmon. More recently, they have been used to study anadromous fish spawning runs in coastal rivers of the southeastern USA (Hewitt and Hightower 2004).

Fish wheels generally consist of a pontoon framework supporting two scoop-like baskets that are turned by the force of the current against two paddle-like wings set at right angles to the scoops (Meehan 1961). The scoops are fitted with cotton, nylon, or wire mesh that is about 4-cm<sup>2</sup> measure. Fish are picked up by the scoops and dropped into a slide that guides them into one or two live wells built into one of the pontoons. Boards may be added to or removed from the paddle assembly to control the speed of revolution. Fish wheels are either anchored in place at the side of the river or fastened to posts driven into the riverbed.

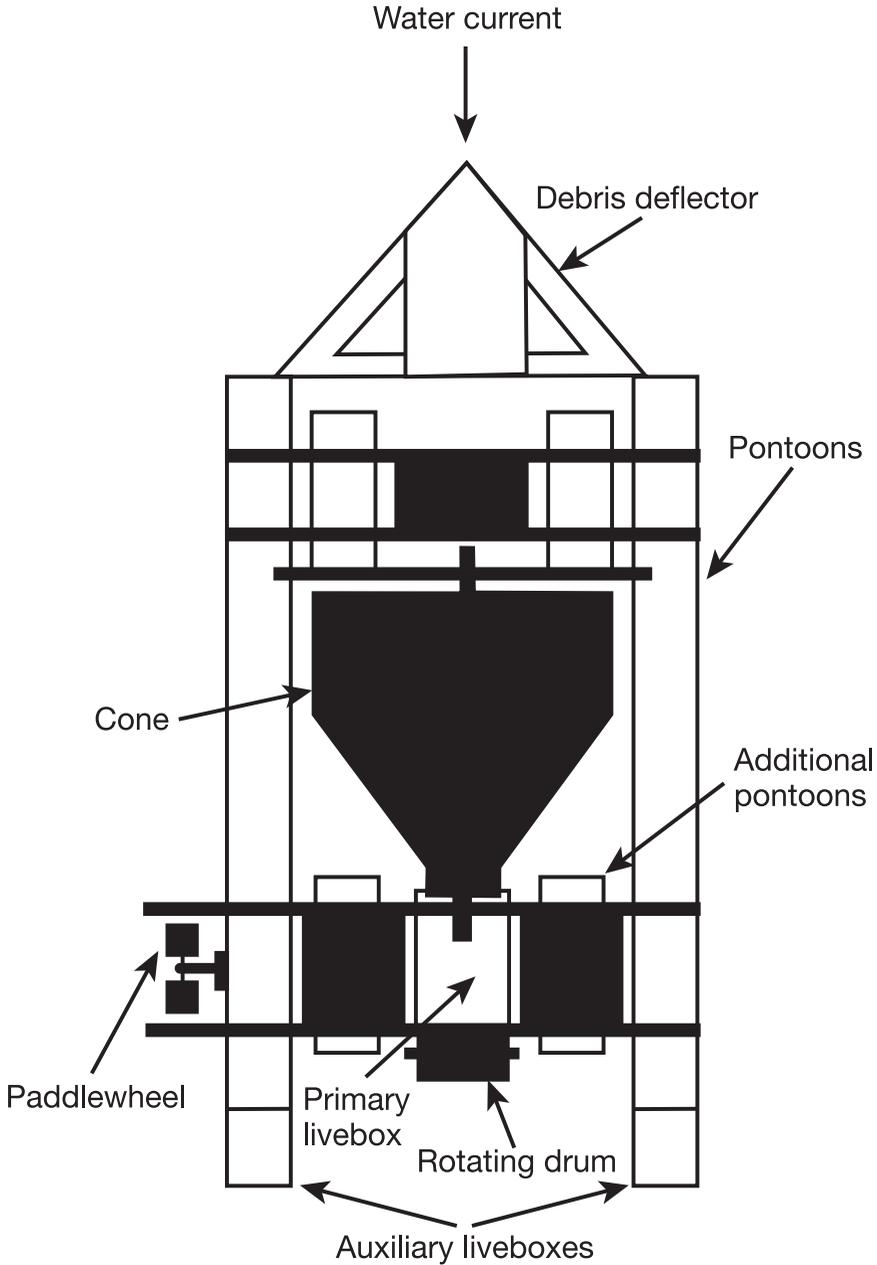
As a sampling tool, fish wheels provide numerous benefits (Underwood et al. 2004). They require little manpower to operate, are relatively safe, provide constant effort, can have high catches, and produce live catches. The utility of fish wheels has made them a regular part of fisheries management programs in many areas (Milligan et al. 1986; Link and English 1996; Cappiello and Bromaghin 1997; Underwood et al. 2004).

### 6.3.6 Rotary-Screw Traps

Rotary-screw traps are passive, water-powered devices that have been used for sampling salmonid smolts migrating downstream (Thedinga et al. 1994; Rayton 2006). Typical rotary-screw traps are constructed with a revolving stainless-steel cone that has 2-mm-mesh openings and is mounted between aluminum pontoons (Figure 6.9). The cone entrance is typically 2.4 m in diameter, and one-half is submerged. An internal screw driven by a paddle wheel rotates the



**Figure 6.8** A fish wheel used to capture fishes as they move upstream near the banks of rivers.



**Figure 6.9** A rotary-screw trap used to capture salmonid smolts during downstream migration.

cone 3–6 revolutions per minute depending on water velocity. Fish passing through the cone are collected in live boxes, where a revolving drum removes debris. These traps are tied to shore and braced in the thalweg with the cone openings facing upstream at constrictions in river channels. Trapped fish can be removed daily to monitor smolt abundance. Screw traps can also be used to recapture marked fish or sample fish for other purposes.

## 6.4 ANGLING GEARS

Passive angling with baited hooks and lines has been used worldwide to catch fishes in both freshwater and marine systems (von Brandt 1964). Angling gears range from a single, baited hook attached with a line to a float or tree branch to commercial longlines that involve a main line (ground line) strung horizontally with many vertical lines (drop lines), each with a baited hook (Figure 6.4). Terminology for these multiple-hook devices varies among geographic locations and target species of fish, but some of the common terms are trotlines, drift lines, setlines, and trawl lines (Rounsefell and Everhart 1953).

Trotlines are used in warmwater inland fisheries (Starrett and Barnickol 1955) and have been used to sample fishes (Thomas and Haas 1999; Diana et al. 2006). No standard design exists for trotlines, but heavy cord usually serves as the main line and lighter cord is used for the drop lines. Catches of fish with trotlines can be affected by the material of the drop lines (i.e., multifilament or monofilament; Johnson 1987), hook size and gape (Arterburn and Berry 2002), and number of hooks. Trotlines can be anchored to lie on the bottom of a lake or stream, or they can be suspended off the bottom with floats. They are often used to capture catfishes with baits such as minnows, cut fish, crayfish, cheese, freshwater mussel meat, or even soap wrapped in aluminum foil. Trotlines have an advantage over hoop nets for collecting freshwater catfishes because they can be used in structurally complex habitats (Stauffer and Koenen 1999; Arterburn and Berry 2002). Trotlines can be selective for common carp if dough or corn is used as bait. Trotlines baited with night crawlers have been used to sample pallid sturgeon and shovelnose sturgeon in the Missouri River and its tributaries.

Longlines are used in marine fisheries and are much larger in scale than are trotlines. Individual longlines can be several kilometers in length and hold thousands of baited hooks. They are known as longlines or setlines in the Pacific Ocean and trawl lines in the North Atlantic (Rounsefell and Everhart 1953; Dumont and Sundstrom 1961). Longlines are fished without anchoring in commercial fisheries for tunas in the Pacific Ocean. Longlines for haddock and Pacific halibut are set on the ocean floor. Suspended setlines baited with ciscoes were used historically on the Great Lakes for lake trout during late spring and early summer. These devices have not been used as sampling devices by fisheries managers because of their large scale, but catches by commercial fishers are often used to monitor trends in abundance of marine stocks (Bell 1970; Schaefer 1970; Rounsefell 1975; Chapter 20).

Several difficulties exist when assessing fisheries based on  $C/f$  data from trotlines or longlines. First, the release of attractants from bait decreases exponentially with time (Løkkeborg 1990, 1994), and temporal changes in the chemical quality of bait is possible (Daniel and Bayer 1987); thus, catch rates decline with time. Second, loss of bait and successive captures of fish cause a decrease in the number of baits available through time; thus, gear saturation and decreased probability of capture are likely to occur (Engås and Løkkeborg 1994). Combined, these factors produce a negative relationship between soak time and capture efficiency. Third, pelagic marine species (striped marlin, spearfishes, and bigeye tuna) are susceptible to capture on sinking (setting) and rising (retrieving) hooks of longlines (Boggs 1992); thus, varying setting and retrieving times increases variability in capture efficiency. Likewise, the timing of longline sets in relation to peak fish-feeding periods affects capture efficiency (Løkkeborg 1994).

The types and sizes of hooks, baits, and lures used on trotlines and longlines affect selectivity of species and size of fish (Erzini et al. 1996, 1997; Broadhurst and Hazin 2001; Hsieh et al. 2001; Arterburn and Berry 2002). For example, catch rates of commercial fishing gears for

undersized fish that must be discarded can be reduced by using larger hooks (Cortez-Zaragoza et al. 1989; Otway and Craig 1993), baits (Løkkeborg 1990; Løkkeborg and Bjordal 1995; Huse and Soldal 2000), and lures (Orsi 1987; Orsi et al. 1993). Further, catch rates of large fish may be unaffected (e.g., Willis and Millar 2001), or may even increase, because of increased gear efficiency (Ralston 1990) and reduced competition between small and large fishes (Løkkeborg and Bjordal 1992). For example, trotlines baited with live black bullheads were up to 28 times more likely to catch flathead catfish than channel catfish in two South Dakota rivers. In contrast, the same trotlines in the same rivers baited with cut common carp were up to 3.5 times more likely to catch channel catfish than flathead catfish (Arterburn and Berry 2002).

Fish captured with hook and line and then released can experience high mortalities (Munoneke and Childress 1994). Ott and Storey (1993) documented hooking mortality for channel catfish caught with trotlines to be less than 20%. Longlines are generally used in commercial fisheries; thus, most mortality-associated research has targeted methods to avoid bycatch (e.g., Trumble et al. 2002), which would eliminate the need to release captured fish. Sea birds dive after bait on hooks as longlines are set, resulting in large numbers of birds killed (Kaiser and Jennings 2002). However, setting lines at night, attaching weights to lines to achieve faster sinking, and trailing a bird “scarer” made of a line with pendants parallel to the longline reduce capture of some sea birds (Misund et al. 2002).

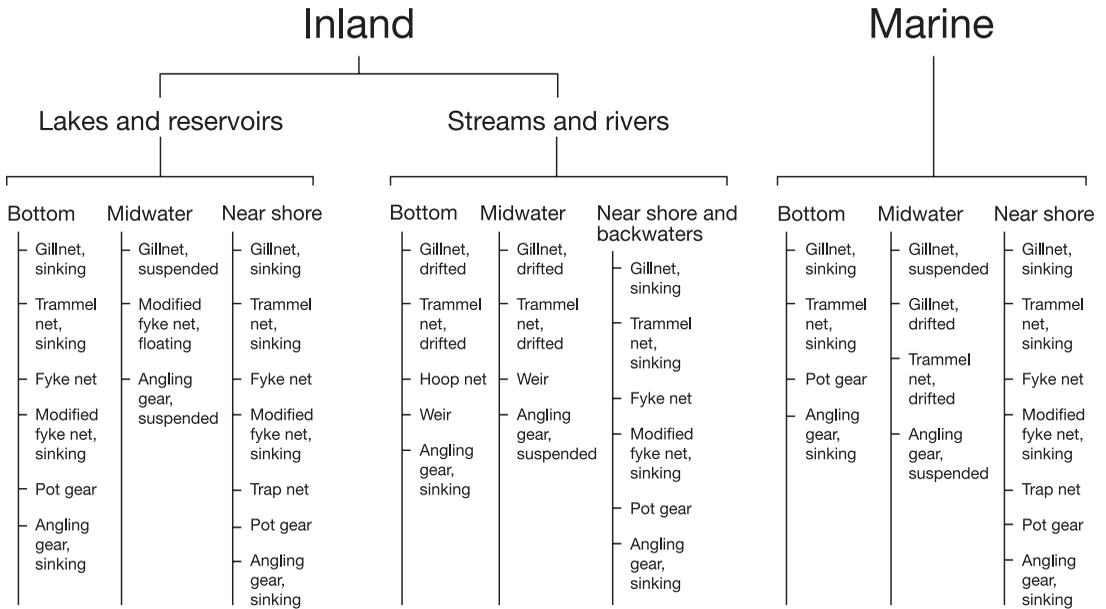
## 6.5 SUMMARY

Passive sampling gears are some of the most useful tools available to fisheries managers and researchers for the appraisal of sport or commercial fisheries or assessment of environmental effects on stocks of aquatic animals (Allen et al. 1960; Hocutt and Stauffer 1980; Bonar et al. 2009). However, problems with sampling variability and gear selectivity are universal. Standardization of sampling devices and strict sampling protocols are necessary to reduce variation among samples and to detect possible changes in stocks that are the result of management efforts or environmental effects (Fisheries Techniques Standardization Committee 1992; Bonar and Hubert 2002; Hubert and Fabrizio 2007). The American Fisheries Society has published *Standard Methods for Sampling North American Freshwater Fishes* (Bonar et al. 2009) in an effort to standardize sampling gears and protocols across North America.

A serious problem associated with many passive entanglement and entrapment gears is continued capture of animals by the gear if it is lost—a process called ghost fishing (Guillory 1993). Although the efficiency of ghost gears decreases through time, the effect can still be large because ghost gears can continue to fish for over 27 months after being lost (Tschernij and Larsson 2003). Continued effort is needed to incorporate more biodegradable material or other technologies into the construction of passive gears used in commercial fisheries and fish population assessments.

A concern with the use of passive sampling gears is the unintended spread of invasive species while sampling (Jacks et al. 2009). Measures to decontaminate sampling gear, boats, and other equipment used in sampling prior to moving among water bodies are advised.

Efforts have been made to identify standard sampling gears for fish in various habitats (Bonar et al. 2009), but such standards are not yet widely adopted. We have provided a decision tree (Figure 6.10) to assist in the selection of possible gears for sampling fish in various habitats. The decision tree identifies potential gears for use in sampling fish in differing inland and marine habitats, but it does not identify gears that are selective for various fish species. When selecting gear and designing a sampling protocol, knowledge of life history and habitat selection by individual



**Figure 6.10** Decision tree illustrating gears that may be used to sample fish in different inland and marine habitats.

species and life stages must be coupled with gears that may be applicable in the habitats used by the targeted fish. It is important to have a sampling design that uses the same gear over time and among locations and to sample at the same locations and same times each year when monitoring fish populations (Hubert and Fabrizio 2007). Generally, sampling designs are developed to minimize variation in *C/f* that is caused by factors other than the true abundance of fish rather than to maximize *C/f*. Passive gears have a long tradition of use for sampling and assessing fish stocks, and their utility will be enhanced in the future with standardization of gears and effective sampling designs.

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