Cyclical Population Dynamics of Self-sustaining Striped Bass in Lake Powell, Utah-Arizona, 1974-1998

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INTRODUCTION

Striped bass were stocked at Lake Powell in 1974 at a time when national interest in establishing this anadromous salt water species in fresh water impoundments was at its peak. State of the art knowledge at the time of stocking indicated that striped bass natural reproduction in freshwater systems was not common, and when it did occur it was not sufficient to provide a self-sustaining sport fishery in most cases. In retrospect, natural reproduction of striped bass was discovered in the lower Colorado River above Lake Havasu from 1966-1970 but was described by Edwards (1974) as limited and seemed to support the body of knowledge previously stated. Natural reproduction was discovered in Lake Mead, Arizona/Nevada in 1974 although that information was not immediately published (Allen and Rhoden, 1979). Following the best information available at time of introduction in 1974 it was thought that striped bass would have to be stocked to maintain a sport fishery and any natural reproduction that occurred would be a beneficial supplement.

During the 1980's it was found that striped bass in Lake Powell and other Colorado River impoundments exist in a situation unique to any other location in the world where successful spawning of striped bass occurs in-lake as well as in the tributaries. The low organic load in the oligotrophic, deep canyon reservoirs allows oxygen to exist at the substrate level which is adequate to allow hatching of striped bass eggs that settle there (Gustaveson et al. 1984). Surface spawned semi-buoyant eggs descend at a rate of one foot per minute and hatch in 2-3 days. In most impoundments in the U. S. eggs not suspended by currents smother due to low oxygen levels. The average mature female striped bass is capable of spawning more than one million eggs. If an unusually high survival rate occurs from eggs to fingerling then striped bass populations are capable of extreme over population in any given year.

The objectives of this paper are to describe the unique nature of striped bass population dynamics in Lake Powell from 1974 to 1998. Various striped bass life history aspects are presented and compared with other waters. The predator/prey relationship between striped bass and threadfin shad is discussed, along with management implications derived from 25 years of research and monitoring.

HISTORICAL BACKGROUND

The striped bass population has been monitored from initial stocking to the present by the Utah Division of Wildlife Resources with funding from federal grants, including Section 8 of the Colorado River Storage Project, Dingell-Johnson Project F-28-R and more recently DJ Project F-46-R.

Striped bass stocking began in 1974 and concluded in 1979 with a total of 815,000 striped bass fingerlings stocked in various locations about the lake (Table 1). Young striped bass grew rapidly, feeding on an abundant forage population of threadfin shad that was previously unexploited in pelagic reservoir areas. Initial growth was rapid nearing the highest recorded growth of any landlocked striped bass population (Gustaveson et al. 1980). The first cohort of stocked striped bass matured in 1979. Mature adults and subsequently young-of-year (yoy) striped bass were collected near the Colorado River inflow where spawning fish would have been attracted by river currents.

Mature adults also staged and spawned near Glen Canyon Dam some 300 km from the Colorado River inflow. Spawned eggs hatched despite the absence of turbulent river currents thought to be necessary to suspend eggs during incubation. Surprisingly, yoy striped bass were found near Glen Canyon Dam in numbers equal to the uplake abundance of yoy. Striped bass yoy less than one month old were not able to be transported over 300 km in the

Table 1. Stocking history of Lake Powell, Utah-Arizona, 1963-1998.

Year	Species	Number	Size	Area	Method
1963	Largemouth Bass	924,000	2-3"	Warm Creek-Aztec	Aerial
	Rainbow Trout	3,000,000	2"	Reservoir Wide	Aerial
	Rainbow Trout	800,000	2-4"	Wahweap Creek	Truck
	Rainbow Trout	35,000	4"	Hall's Crossing	Truck
	Kokanee Salmon	600,000	1-2"	Kane Creek	Truck
1964	Largemouth	1,000,000	2-3"	Wm Crk-Last Chance	Aerial
	Largemouth Bass	250,000	2-3"	Mouth Escalante	Aerial
	Largemouth Bass	250,000	2-3"	Rincon	Aerial
	Largemouth Bass	500,000	2-3"	Bullfrog Creek	Aerial
	Rainbow Trout	3,000,000	2-3"	Dam-Bullfrog Creek	Aerial
	Rainbow Trout	325,650	5-8"	Hite	Truck
	Rainbow Trout	365,730	5-8"	Wahweap Creek	Truck
	Kokanee Salmon	35,000	2-3"	Wahweap Creek	Truck
	Black Crappie	350	6"	Wahweap Creek	Truck
	Black Crappie	9,000	3"	Wahweap Creek	Truck
1965	Rainbow Trout	4,383,525	2-3"	Reservoir Wide	Aerial
	Rainbow Trout	40,000	5"	Wahweap Creek	Truck
	Black Crappie	30,000	1"	Wahweap Creek	Truck
	Black Crappie	4,700	4"	Wahweap Creek	Truck
1966	Rainbow Trout	2,140,000	2-3"	Reservoir Wide	Aerial
1967	Rainbow Trout	344,049	4-5"	Wahweap-Warm Creek	Aerial
	Rainbow Trout	103,205	4-5"	Hall's -Bullfrog	Barge
	Rainbow Trout	102,590	4-5"	Red Canyon	Barge
1968	Rainbow Trout	201,364	3-5"	Wahweap Creek	Barge
	Threadfin Shad	1,500	1-4"	Wahweap Creek	Truck
1969	Rainbow Trout	251,238	5"	Wahweap Creek	Barge
	Threadfin Shad	200,000	Egg-fry	Wahweap Creek	Spawn mats
1970	---------------------------NO STOCKING-----------------				
1971	Rainbow Trout	281,000	4-5"	Bullfrog	Barge
	Rainbow Trout	527,000	4-5"	Wahweap Creek	Barge
	Rainbow Trout	40,000	4-6"	Warm Creek	Barge

Table 1. Continued.

Year	Species	Number	Size	Area	Method
1972	---------------------------NO STOCKING-------------------				
1973	Rainbow Trout	233,400	5"	Wahweap Creek	Truck
1974	Striped Bass	49,885	2-3"	Wahweap Creek	Truck
1975	Striped Bass	94,878	2-3"	Wahweap Creek	Truck
1976	Rainbow Trout	50,000	3-6"	Wahweap Creek	Truck
	Striped Bass	35,752	2-3"	Wahweap Creek	Truck
	Striped Bass	19,305	2-3"	Bullfrog	Aerial
1977	Rainbow Trout	18,600	5"	Wahweap Creek	Truck
	Striped Bass	86,003	2-3"	Wahweap Creek	Truck
	Striped Bass	52,650	2-3"	Bullfrog	Aerial
1978	Striped Bass	169,469	2-3"	Wahweap Creek	Truck
	Striped Bass	84,821	2-3	Bullfrog	Aerial-Truck
1979	Striped Bass	222,550	2-3"	Wahweap Creek	Truck
1980	Rainbow Trout	13,210	6"	Wahweap Creek	Truck
1981	---------------------------NO STOCKING-------------------				
1982	Smallmouth Bass	3,100	2-4"	Warm Creek	Truck
	Smallmouth Bass	59	10-15"	Warm Creek	Truck
1983	---------------------------NO STOCKING-------------------				
1984	Smallmouth Bass	26,600	2-4"	Wahweap-Warm Creek	Truck
	Smallmouth Bass	4,000	2-4"	Stanton Creek	Aerial
1985	Smallmouth Bass	13,289	2-4"	Wahweap Creek	Truck
	Smallmouth Bass	12,389	2-4"	Antelope Canyon	Truck
	Smallmouth Bass	22	10-15"	Antelope Canyon	Truck
	Smallmouth Bass	31,995	2-4"	Rincon	Aerial
	Smallmouth Bass	19,390	2-4"	Good Hope Bay	Aerial
	Smallmouth Bass	26,328	2-4"	Neskahi Canyon	Aerial
	Smallmouth Bass	702	10-15"	Hite-Dirty Devil	Truck
1986	Smallmouth Bass	12,758	2-4"	Escalante River	Aerial
	Smallmouth Bass	8,136	2-4"	Piute Farms Wash	Truck
	Smallmouth Bass	6,123	2-4"	Wahweap Creek	Truck

Table 1. Continued.

Year	Species	Number	Size	Area	Method
1987	Smallmouth Bass	220	3-6"	Wahweap-Warm Creek	Truck
	Smallmouth Bass	24,200	2-3"	West Canyon	Aerial
	Smallmouth Bass	7,200	2-3"	Nokai Canyon	Truck
		3,150	2-4"	Piute Farms	Truck
1988	Smallmouth Bass	20,536	2"	Knowles/Cedar Cyn	Aerial
	Smallmouth Bass	24,643	2"	Llewellyn/Cottonwood	Aerial
	Smallmouth Bass	4,307	2"	Middle Rock Creek	Aerial
	Smallmouth Bass	10,745	2"	San Juan (mouth)	Aerial
	Smallmouth Bass	10,800	2"	Navajo Canyon	Aerial
1989	Smallmouth Bass	21,002	2"	Trachyte Canyon	Aerial
	Smallmouth Bass	2,394	2"	Warm Creek (mouth)	Boat
1990	------------- NO STOCKING -------------				
1991	------------- NO STOCKING -------------				
1992	Black Crappie	7,000	2"	Warm Creek	Truck
1993	Black Crappie	10,000	2"	Wahweap Bay	Truck
1994	------------- NO STOCKING -------------				
1995	------------- NO STOCKING -------------				
1996	------------- NO STOCKING -------------				
1997	------------- NO STOCKING -------------				
1998	------------- NO STOCKING -------------				

amount of time elapsed since birth (Gustaveson et al. 1984). Striped bass yoy have consistently been collected in large numbers near the inflow and near Glen Canyon Dam with only modest numbers found in midlake areas. Stocking was curtailed in 1979 to allow the magnitude of natural reproduction to be assessed. It was evident within two years that reproductive success of large proportions was taking place.

It is thought that current created by entrained water released through penstocks of Glen Canyon Dam is detected by striped bass causing attraction and spawning aggregations. Prespawning staging of mature fish commonly have been found near the dam, and striped bass eggs have been collected with tow nets within 6 km of the dam.

Unlimited reproduction of striped bass dramatically increased population size and placed an overwhelming predatory burden on threadfin shad which is the only pelagic clupeid forage fish present in Lake Powell. Trawling results showed that threadfin shad were eliminated from reservoir open water zones for most of the 1980's. Adult shad (>150 mm) were able to survive in sanctuaries in warm turbid backwaters where striped bass adults were unable to enter because of thermal limitations and where juvenile striped bass were not large enough to consume them. Absence of pelagic shad caused a decline in physical condition of adult striped bass and eventual starvation in some years.

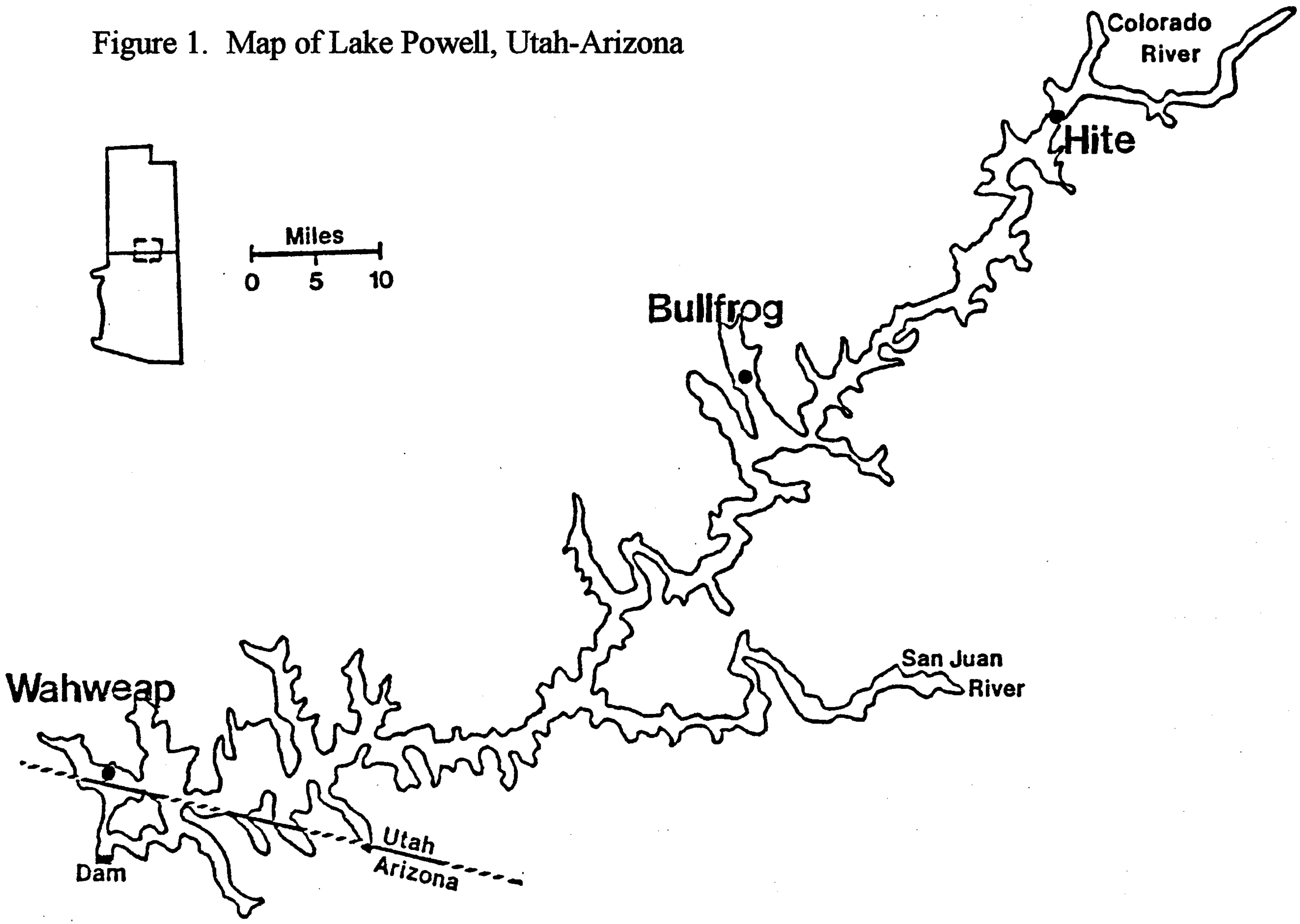
During initial striped bass introductions (1974-1979), the creel limit was 2 fish. With discovery of natural reproduction the creel limit was raised to 4 fish in 1983. A peak in striped bass harvest and rapid decline in physical condition led to another limit increase to 10 fish in 1984. Small average total length of striped bass in the low shad years of the 1980's led to a 1990 increase in creel limit to 20 fish, in attempt to harvest small fish. Finally, an abundant 1991 striped bass year class perched on the edge of starvation resulted in the removal of the creel limit altogether in 1993. Regulations were further liberalized when chumming with dead anchovies was allowed to increase harvest of striped bass in 1996 and the simultaneous use of two fishing rods was allowed with the purchase of a 2-pole fishing stamp in 1997.

STUDY AREA

Lake Powell is impounded by Glen Canyon Dam on the Colorado River, 9.7 km south of the Utah/Arizona border (Figure 1). The 300 km-long reservoir is confined to the deep narrow canyon of the Colorado River and its tributaries. Most of the 2,930 km of shoreline is comprised of sandstone cliffs and talus slopes. Only a few side bays offer relief from the towering vertical canyon walls. Average depth of the reservoir is 50.9 m (Johnson and Merritt 1979) with maximum capacity at $3.32x10^8$ m^3.

Lake Powell is a warm meromictic reservoir with stratification generally beginning in April and persisting into December. The deepest water below penstock levels seldom mix with the active upper layers which are greatly influenced by a lake-long density current. Main channel pelagic surface temperatures range between extremes of 6.7 and 29.4 C. Visibility is typically 3-9 m although secchi disk readings as high as 14 m have been recorded by UDWR personnel. Chlorophyll[a] normally ranges from 1.8-2.5 ug/l with levels as high as 5 occurring in isolated locations (Paulson and Baker 1983, Sollberger et al. 1989). Plankton densities seldom exceeded 20/l in main channel locations (Sollberger et al. 1989) with higher densities found where major tributaries enter the reservoir and in side canyons with perennial streams or flash flood events increase nutrient loading. Fluctuating lake levels cause redistribution of nutrients trapped in lake bottom sediments that are exposed as water levels decline. Constantly flowing tributaries or storm events cut through the sedimentary layers and wash sediment and nutrients back into the reservoir where

Figure 1. Map of Lake Powell, Utah-Arizona



they are once again biologically available for plankton production.

METHODS

Striped bass data were evaluated over the past 24 years. Fish were collected by gill netting, electrofishing, ichthyoplankton tows, midwater trawls, with hook-and-line, and during creel surveys. Fish were measured to total length (TL) with the caudal fin squeezed on the measuring board. Fork length, used to determine condition factor (Kfl), was obtained by multiplying total length by a factor of 0.93. Gill net catch was enumerated as striped bass caught per 1000 ft^2 of gill net set for 12 h. Food habits were taken from each fish at time of capture and reported as percent occurrence. Scales for age and growth were taken from a point below the lateral line and at the tip of the pectoral fin. Stage of maturity was occasionally taken from a subsample of fish collected by all techniques at various times throughout the years.

AGE AND GROWTH

From 1975-1979 yearling striped bass grew faster than striped bass in saltwater and in most freshwater populations (Table 2). Shad were abundant in the pelagic zone and the newly introduced striped bass were not numerous enough to deplete pelagic forage fish. This period demonstrates maximum growth potential of striped bass in Lake Powell with unlimited forage resources.

Greatest growth occurred during the first three years of life. Annual growth increments from 1980-1984 were 227, 202, 126, 79, 39, 33 and 80 mm for Ages 1-8, respectively. In contrast, Atlantic Coast striped bass in Chesapeake Bay and

Table 2. Selected back-calculated growth estimates of yearling striped bass.

Author	Location	Actual or back calculated total length (mm) at age I
Present study 1975-1979	Lake Powell	253
Present study 1980-1984	Lake Powell	227
Present study 1985-1989	Lake Powell	148
Present study 1990-1997	Lake Powell	202
Saul et al. 1983	Cherokee, TN	217
TVA 1975	Cherokee, TN	175
Higginbotham 1979	Watts Barr, TN	182
Axon 1979	Herrington Lake, KY	280
Erickson et al. 1971	Keystone, OK	279
Bason, 1971	Delaware Estuary	109
Mansueti 1961	Chesapeake Bay, MD	139

Pacific Coast fish from the San Joaquin Delta averaged about 120 mm in annual growth increment for the first three years, 60-70 mm between ages 4 and 6, and 50 mm annually after age 8 (Setzler et al. 1980). Lake Powell fish grew faster than ocean fish prior to maturity and slower following maturity. The broad range of types and sizes of forage available to ocean fish explain these differences.

Table 3 depicts the growth history of Lake Powell striped bass in 5 year blocks. The 1975-1979 block showed maximum growth. Natural reproduction, beginning in 1979, resulted in a geometric increase in striped bass numbers. Growth decreased slightly due to intraspecific competition during this period (1980-1984) but was only 30 mm less for 4 year old fish. Many individuals obtained large size, and reached ages of up to 10 years. These larger striped bass had a mouth gape size large enough to consume one-pound carp which became a staple in their diet. Most of these large fish attained lengths >600 mm before shad numbers declined and continued to grow after switching to a carp diet. Growth of younger striped bass diminished as shad numbers declined.

The period 1985-1989 marked a dramatic decrease in growth rates as striped bass numbers peaked, and shad were eliminated from open water zones by intense predation. Total back-calculated length at each age class dropped 100-225 mm less than previously seen in 1975-1979 (Table 3). Striped bass were shorter, did not live as long, and some never obtained sexual maturity. Most of the population was composed of immature fish 300-400 mm TL which were as young as Age 2 or as old as Age 6. Stunted striped bass resorted to eating plankton in the pelagic zone after the annual crop of shad was consumed soon after hatching.

Slow growth and small size of striped bass (1985-1990) allowed the largest (>150 mm) shad to escape predation and produce measurable shad year classes in 1990 and 1991. Striped bass growth gradually recovered during the period 1990-1997 as

Table 3. Back-calculated growth of striped bass at Lake Powell, 1975-1997. Mean estimated total length (mm), with age classes not separated.

	AGE CLASS									
YEARS	1	2	3	4	5	6	7	8	9	10
1975-1979	253	440	564	663	690					
(n)	(939)	(324)	(111)	(41)	(1)					
1980-1984	227	429	555	634	673	702	735	815	967	946
(n)	(865)	(786)	(680)	(587)	(422)	(285)	(112)	(22)	(4)	(3)
1985-1989	148	269	386	438	511	604	707			
(n)	(597)	(473)	(345)	(179)	(50)	(11)	(1)			
1990-1997	202	356	434	478	511	542	558	603	635	650
(n)	(590)	(311)	(178)	(114)	(71)	(38)	(17)	(2)	(1)	(1)

shad forage was once again available in open water zones during the majority of these years. Growth over the first three years of life, when growth increment is the greatest, was the source of most improvement. Size at Age 2 increased 87 mm over the previous 5 year period. Growth of older fish was essentially the same with Age 5 fish registering 511 mm in both of the latter periods. Again, fish were living longer during the 1990-1997 period as forage became more available. One 10-year-old fish measured 650 mm, while a fish of similar age in 1980-1984 measured 946 mm showing an overall reduction in growth rate.

The 1990-1997 period was characterized by limited forage with striped bass not growing as fast or as large as the first group that was stocked in the lake. They attained sexual maturity when forage was adequate and the majority of fish old enough to spawn in 1996 did so. During 1995-1996 shad were found in open water zones during both years. Striped bass growth increased accordingly and approached growth rates of the cohorts stocked in the 1970's. In 1996, yoy again approached 300 mm TL during their first year.

In low forage years yoy might spend the first winter and spring as 90-125 mm fish and then double in length the next year if shad are available. Differential growth among cohorts is common depending upon forage abundance.

Most adult fish measured >500 mm. In any year this size group can be a combination of fast growing 1-year-olds, to stunted 7-year-old fish. Growth compensation occurs when slower growing young fish grow more rapidly in later years (Carlander 1969). Striped bass growth rate was determined by population density in relation to forage abundance in Lake Powell.

The tremendous size of the lake and complex morphology allowed differential growth to occur between lake areas. In 1997 good forage conditions in the upper lake resulted in excellent growth, with fall-sampled yearlings ranging between 300-400 mm. In the upper lake yoy stripers ranged from 230-295 mm. During the same sampling period in the lower lake yoy and yearlings overlapped in the 200-280 mm range. Some yearlings were the same size (340-380 mm) as their uplake counterparts. If forage remains limited and striped bass are restricted to a plankton diet, then even two-year-old fish overlap in size with yoy. Migration or differences in behavior results in discrepancies in growth among individual fish.

Faster growing striped bass were frequently shorter lived than slow growing fish. Long-lived trophy fish greater than 15 pounds typically show a first growth ring from scale analysis that corresponds to small size (100-200 mm) at annulus formation. Conversely, fish noticeable larger than siblings from the same cohort often show first growth rings that indicate a size larger than 250 mm at first annulus formation. A 250-mm striped bass has a scale that measures 65-70 mm at a magnification of 24 times. These fast growing fish do not often persist longer than 5 or 6 years. Only a small number of individuals live longer than 6 years with the majority of the population succumbing to natural mortality or sport harvest before that time. Striped bass over 20 pounds consistently show an initial growth ring that corresponds to relatively small size at first annulus formation and consistent growth each year thereafter. Still the 575 mm fish has a scale radius of 200 mm (24 X magnification) regardless of how old it is.

FOOD HABITS

Lake Powell striped bass preferred threadfin shad over any other food item available. When shad were not readily available striped bass adults ate crayfish as a secondary food source (Table 4) while juvenile striped bass consumed zooplankton (Table 5). Other fish species were eaten only occasionally.

In years when shad were limited in open water striped bass were forced to consume alternate prey. The schooling nature of striped bass makes them extremely proficient at feeding in open

Table 4. Percent occurrence of food items in striped bass(TL >= 500 mm) stomachs that contained food, collected from gill nets at Lake Powell, Utah,1989-1998.

Year	89	90	91	92	93	94	95	96	97	98
Sample size	11	10	37	32	46	39	25	65	35	51
number empty	6	4	15	18	26	28	15	29	25	40
Food item - Percent Occurrence in stomachs containing food										
crayfish	60	33	14	7	20	45	20	-	10	27
shad	80	67	86	79	55	36	80	100	70	54
zooplankton	-	-	-	7	5	9	-	-	-	-
centrarchid	-	17	-	-	20	9	-	-	10	9
unid. fish	-	-	-	7	-	9	-	-	10	-
carp	-	-	-	-	5	-	-	-	-	-

Table 5. Percent occurrence of food items in striped bass (TL < 500 mm) stomachs that contained food, collected from gill nets at Lake Powell, Utah, 1989-1998.

Year	89	90	91	92	93	94	95	96	97	98
Sample size	235	169	102	131	166	179	237	382	352	141
Number empty	101	68	51	79	69	68	82	163	170	83
Food item - Percent occurrence in stomachs containing food										
crayfish	10	11	-	-	3	-	-	-	-	-
shad	34	73	86	65	79	64	97	79	65	62
zooplankton	55	14	6	27	15	35	1	21	34	29
centrarchid	2	-	-	-	1	-	1	1	-	9
unid. fish	4	5	4	6	3	1	2	3	1	3

water and remarkably inefficient at foraging along the shoreline for crustaceans or sunfish. If littoral or benthic forage organisms are found and consumed there may be only a few individuals within the striped bass school that benefit. Without schooling pelagic forage fish the health of the entire striped bass school suffers. Without question the health of the striped bass population rises and falls with the peaks and valleys in the threadfin shad population.

Larval striped bass eat zooplankton. Small rotifers are often the first food consumed but after a few days nauplii copepods are targeted. As striped bass grow larger they eat a variety of invertebrates from adult copepods to cladocerans and insects. At approximately 95-100 mm striped bass convert to a fish diet, if available. Striped bass then continue to eat clupeid fish throughout their life unless forced to find alternate forage.

When shad have disappeared from the pelagic zone of Lake Powell all sizes of striped bass from juveniles to adults revert to eating zooplankton. Juvenile striped bass are able to maintain body condition but adults gradually waste away without pelagic forage fish for sustenance.

Feeding Behavior

An abundance of larval shad in pelagic zones allow striped bass to feed leisurely as they travel in straight lines at low speeds consuming small shad at will. Limited swimming ability of larval shad make escape from striped bass difficult. Surface feeding activity occurs as 100-5000 striped bass gently roll and porpoise in unison. These "boils" only simmer as striped bass roll and slurp on top. Disturbance by boats cause striped bass schools to sound and then reappear a few hundred yards away as feeding resumes in a different direction.

As shad grow in size and develop stronger swimming ability the surface action gets more intense as striped bass corral shad against the surface or trap them near shore. The tendency for shad to "ball up" in a tight school when predators approach allows striped bass to herd and trap shad schools. The trapped shad school is repeatedly probed by striped bass working together to eat, injure and kill as many shad as possible. Shad are often slashed by the jaws and stunned by the powerful caudal fin during such encounters. Striped bass capture most shad at the surface creating a highly visible disturbance with water spouts and a boat wake-like wave as stripers line up shoulder to shoulder to feed. When the attack commences the surface activity is intense and visible for many hundred meters as water is thrown high in the air. Surface feeding boils last from a few seconds to as long as three hours. Duration is probably determined by shad abundance. Many shad allow a longer feeding period while few shad may be consumed or lost from sight in a few seconds.

Surface boils only occur when shad are present. In years when shad numbers are limited and eventually eliminated from the open water, no striper boils are seen. When shad are abundant boils are common and predictable. Striped bass often feed at the same time in the same location on a daily basis. Striped bass habitually return to a successful feeding spot every day until the forage is consumed or escapes.

Both shad and stripers are tightly bunched as they begin the daily feeding ritual. Normally, about one-half hour after first light shad form schools after spending the night randomly distributed in the water column. This shad schooling behavior attracts striped bass and feeding begins. As shad schools are repeatedly attacked, large schools fragment into smaller groups. Fragmentation of shad schools also causes striped bass schools to break up as groups of striped bass chase after small groups of shad. An original feeding event, one-hectare in size, can dissolve into scattered striped bass feeding in many different directions over a square kilometer. When feeding ceases both shad and striped bass regroup.

If striped bass are satiated they may not eat for the rest of the day. More likely they will randomly feed again near mid-day and then again in the evening just before dark. After dark, shad schools disperse and boils are not likely. Striped bass are effective nocturnal feeders and feed on shad subsurface at night.

In times when forage is abundant, boils may be rare or half-hearted because shad are easily obtained and schooling efforts are not required to obtain food. Perhaps surface feeding action is at its peak when shad are common but not abundant. Striped bass must now work hard to corner shad for effective feeding opportunities. As shad become scarce, surface feeding opportunities decrease. At the other extreme, malnourished striped bass cannot compete with healthier more aggressive fish and drop out of the school. Forced to forage on their own individual striped bass are inefficient and are forced to expend even more energy. The end result is a decline in physical condition. School fish may be fat and healthy while solitary fish decline in condition. It is possible to catch striped bass in the same area and find remarkable differences in condition between fat school feeding fish and thin individuals.

Total elimination of shad from the pelagic zone results in adult striped bass leaving the warm surface layers where shad once resided to seek cooler water at or below the thermocline where less metabolic demand is placed on fish stressed from lack of food. In Lake Powell there is an almost total absence of forage below the thermocline since most small fish and plankters live in the epilimnion. Once striped bass seek cool depths to preserve energy they are doomed to starvation.

Zooplankton is abundant enough to provide feeding opportunities for juvenile striped bass regardless of shad abundance. Wind, wave action and associated currents concentrate large schools of cladocerans providing a rich, but scattered, plankton forage prey base. All fish including striped bass search out and utilize these zooplankton concentrations. An individual stomach sample from a 275 mm yearling striped bass may contain thousands of plankters that weigh as much as 50 g. In years when shad are available plankton is ignored in favor of a fish diet, but juvenile striped bass can thrive on a zooplankton diet. Mature fish have been found with a similar large bolus of plankton in the stomach, but energy expended pursuing zooplankton apparently exceeds energy gained since these plankton-eating adult fish consistently have low K factors.

Seasonal Feeding

In the fall shad seek shallow water to avoid predation. Striped bass will often remain in a cove and trap shad for extended periods. The predators rest in deep water at the mouth of the cove and attack any forage that attempts to leave. The vigil is interrupted by periodic feeding sprees as striped bass rush into shallow water and eat their fill.

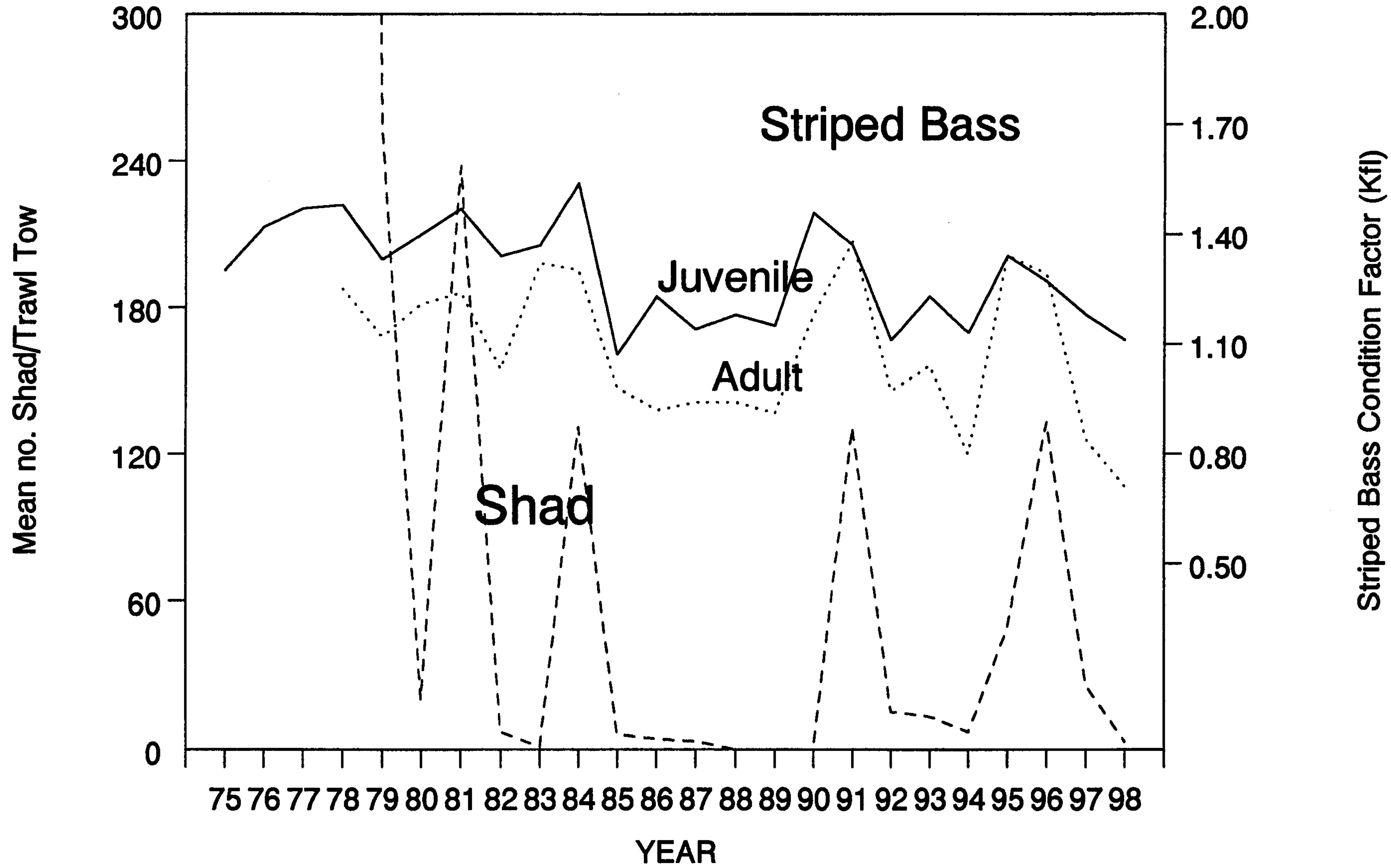
Cold temperatures force striped bass into semidormancy. In winter feeding is of short duration and infrequent at best. In years when fat reserves are high, dormancy is prolonged. When body fat is absent and food is scarce, striped bass tend to move constantly in search of food.

Midsummer feeding opportunities when surface water temperatures exceed 26 C are mostly limited to juvenile striped bass; however, young adult stripers weighing up to 2 kg have been seen "boiling" in these extreme conditions. Apparently, temperature acclimation is possible allowing healthy adults to take advantage of foraging opportunities if they do not stay in the warm epilimnion for extended periods of time. These boils are normally of short duration. Diving schools of young adult striped bass have been tracked on sonar as they retreated to the cooler thermocline.

PHYSICAL CONDITION

Healthy striped bass in Lake Powell exhibited a K(fl) factor of 1.2 to 1.3. Really robust fish were 1.4 to 1.5. When K factor declined below 1.1 striped bass were noticeably thin.

Figure 2. Condition factor of adult and juvenile striped bass compared to pelagic shad abundance, 1975-1998.



Fish with K factors less than 1.0 have deteriorating flesh and less desirable fillets.

Striped bass condition mirrored shad abundance (Figure 2). The initial, expanding striped bass population (1975-1981) was consistently healthy with K factors near 1.3 despite some cyclical swings in shad abundance. Prior to striped bass establishment shad exhibited a population peak every third year with two moderate production years in between. Shad peaks in 1981 and 1984 allowed high survival of striped bass year-classes which subsequently placed tremendous predatory pressure on shad in succeeding years. Condition of adult striped bass declined in 1982 and 1985-1989 to levels where harvested fish were unacceptable to anglers.

Juvenile striped bass were able to maintain better condition than adults by foraging on plankton if needed. Juvenile striped bass occupied the same niche as YOY shad in the warm epilimnion and eliminated shad forage from the pelagic zone in years when juvenile striped bass were numerous. Adult striped bass required cooler temperatures and were forced deeper in the stratified reservoir (Schaich 1979). The ontogenetic separation of different sizes of striped bass favored juvenile fish at the expense of adults because juveniles could reside in the same warm water zone as their prey. This juvenile-dominated imbalance in the striped bass population continued through the 1980's.

High striped bass numbers combined with drought conditions to keep the shad population low. From 1985-1990 there was no detectable shad population in open water when sampled with midwater trawl. Adult shad found thermal sanctuaries from striped bass in shallow, turbid water in the backs of the coves. Shad venturing into open water were vulnerable to predation. The end result was a stunted striped bass population that did not grow to maturity. Adult shad too large to be consumed by stunted striped bass were stockpiled in thermal sanctuaries until conditions were finally right for a shad population recovery. A good shad spawn in 1990 resulted in a population large enough to markedly increase juvenile striped bass condition. Most shad were consumed before the few remaining adult striped bass could feed on them and therefore, shad were not measurable by trawl in open water. It was not until 1991 that the shad recovered enough to provide forage for all striped bass and for shad to be detected in mid water trawl sampling (Figure 2).

Since 1991 striped bass condition and shad numbers have fluctuated. Juvenile striped bass still maintained a healthy condition with a combined shad/plankton diet. The shad population has been measurable with mid-water trawl every year since 1991 with peaks in 1991, 1995 and 1996. Adult striped bass physical condition surpassed that of juvenile fish in 1991 and 1996 (Figure 2). When both large and small striped bass compete for forage fish in the open water the larger adults have the competitive advantage. During the shad peaks of 1991 and 1995-6 adult K factor was equal to or greater than juvenile K factor despite The usual foraging advantage of juvenile striped bass. When average catch of at least 100 shad per trawl tow occurs adults successfully compete with juveniles. That abundance of shad forage has only occurred 3 times in the past 16 years.

RECRUITMENT

During spring 1997 a school of prespawn striped bass was located in Wahweap Bay. Mature females from that aggregation averaged 674 mm and 2900 g. The ovaries were olive green-colored, large and viable. Fat reserves were consistently 0 rated on a scale of 0-4 (Goede 1988). Apparently energy reserves were channeled into production of gametes. Spawning occurred about May 20, 1997. Average weight of females dropped 500 grams following spawning with a corresponding drop in K factor from 1.3 to 1.1.

Shad population peaks in successive years, 1995 and 1996, were unprecedented since striped bass became established by natural reproduction. It appeared that a precarious balance occurred between striped bass predation and shad abundance beginning with the shad peak in 1991. The single shad peak year of 1991 did not result in survival of an excessively large number of juvenile striped bass since most adult fish did not attain spawning condition. Conversely, two years of improved forage conditions (1995-1996) resulted in high recruitment of 1996 year-class striped bass.

Young-of-year population abundance was measured by annual electrofishing sampling each September and gill netting each November (Figure 3). The schooling, pelagic nature of striped bass makes any sampling scheme vulnerable to misrepresentation depending on the behavior of striped bass during the sampling period. Peaks in abundance measured by one survey have not necessarily been corroborated by other surveys in the same year. The 1991 peak capture of yoy in gill nets resulted from 2 nets of 10 total set at one downlake location where yoy were abundant. The 38 other nets included in that survey captured only a few yoy while two nets caught over 100 yoy each day. The result was a yoy peak in 1991 even when averaged over the entire survey.

Spawning production in 1996 measured by electrofishing found record high numbers of yoy striped bass at all locations with the exception of Warm Creek, the station closest to the dam. When compared to yoy captured during fall netting a corresponding peak is seen. In some years a spike in yoy numbers is seen in one survey or the other without corroboration from the other survey.

The strength of the 1996 year-class was depicted by the results of both surveys. Young-of-year striped bass caught electrofishing was at the highest level ever recorded. Gill net catch of yoy was also near record proportions. Based on both surveys, the 1996 striped bass year-class was present at all locations in numbers never before seen in over 20 years of sampling (Figure 3).

The 1996 year-class was extremely numerous as yearlings in 1997 based on creel survey reports but not remarkable when

Figure 3. Comparison of young-of-year striped bass collected in fall gill net and electrofishing surveys, 1979-1998.

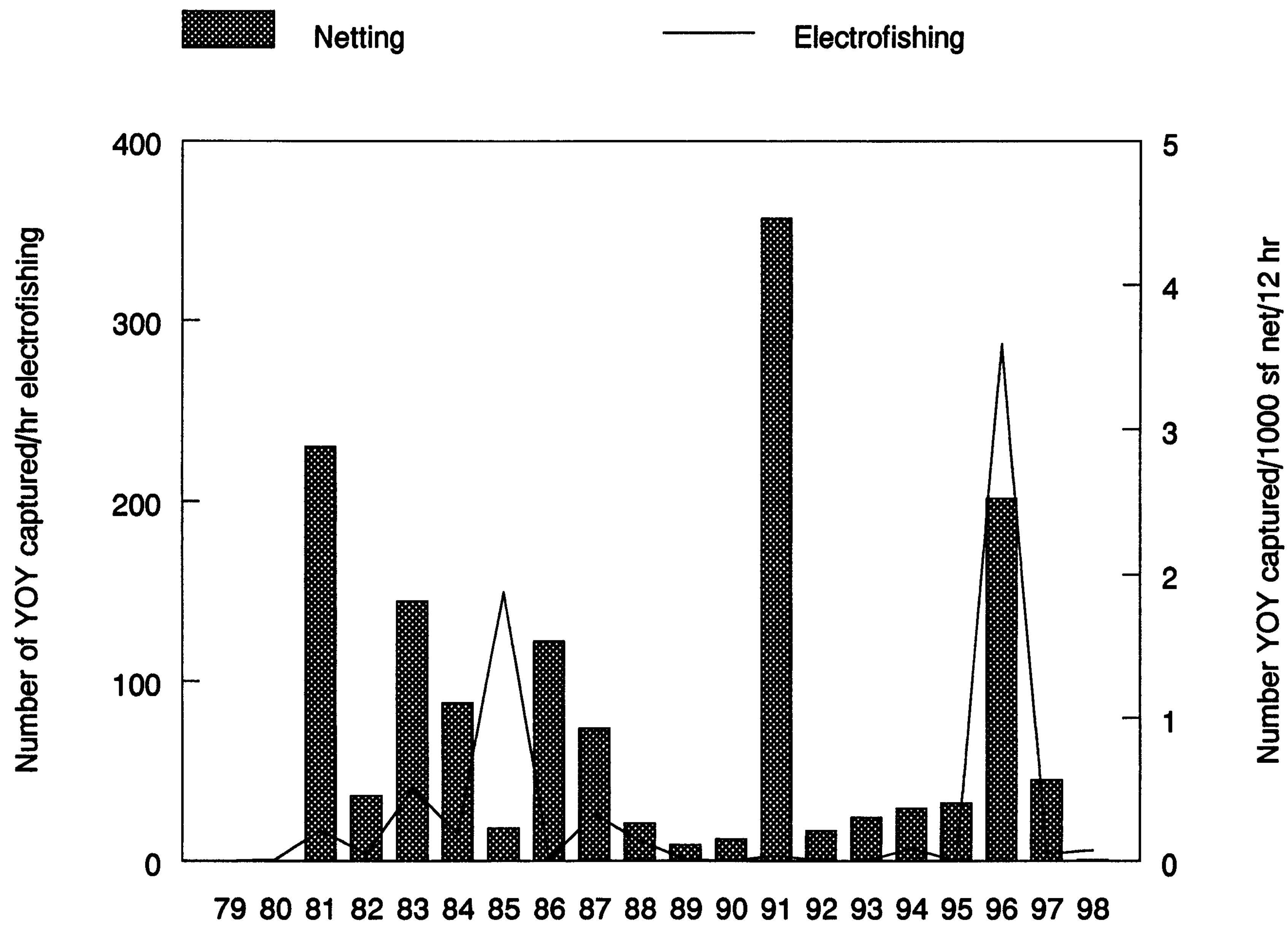
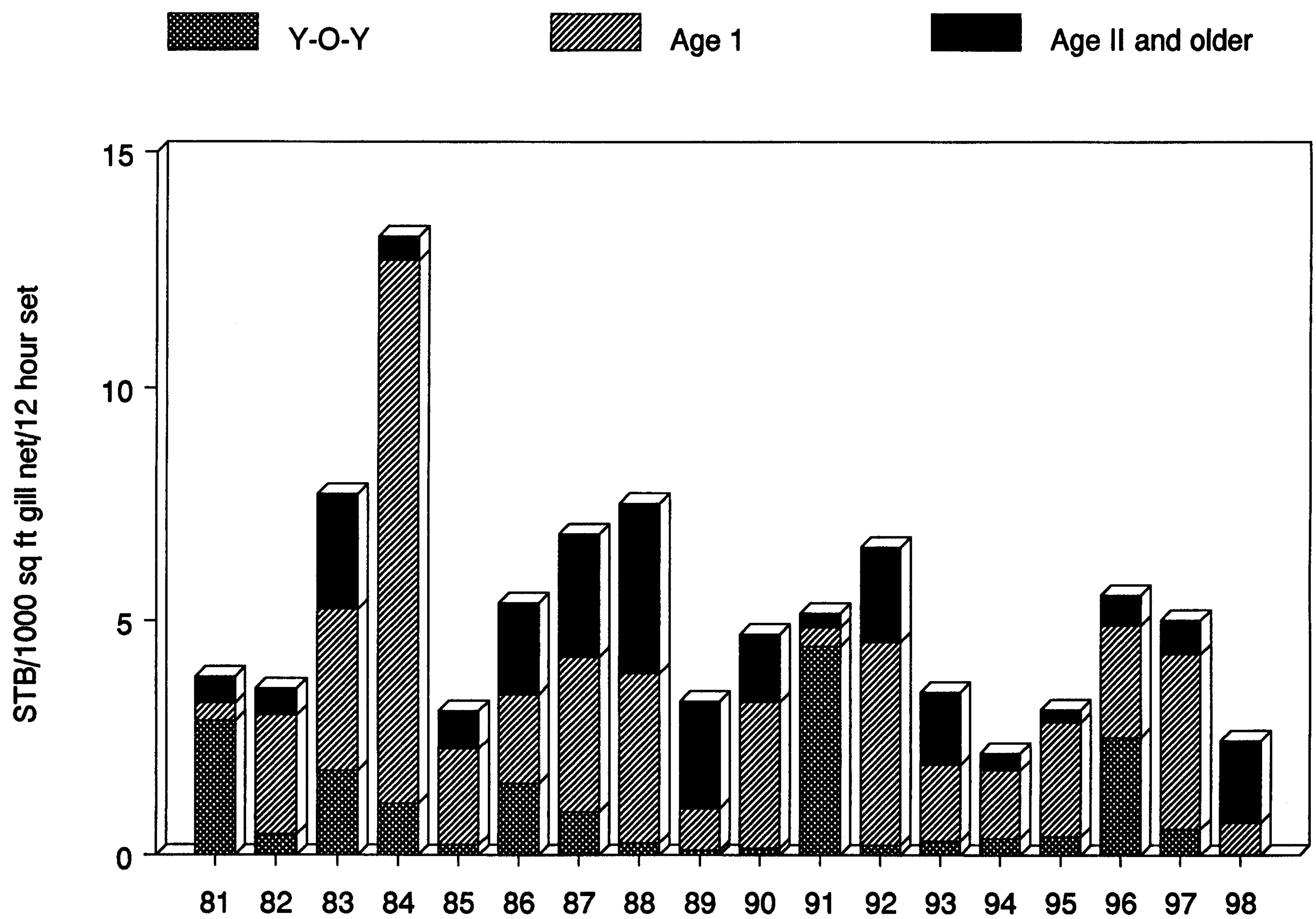


Figure 4. Comparison of yearling striped bass and pelagic shad abundance at Lake Powell, 1981-1998.

Figure 5. Abundance of various age classes of striped bass collected from fall gil net survey 1981-1998.



measured by fall gill net catches (Figure 4). The population peak represented that year was similar to many similar peaks over the past decade. As forage declined in 1997 and collapsed in 1998 the year class began to lessen in number.

Striped bass abundance peaks during and/or after a shad peak (Figure 5). The population crashes after the peak and then builds for 3 to 4 years to the next peak and subsequent crash. Numbers do not necessarily correlate to fish size as old fish may still be less than 20 inches during periods of shad shortage. During the past 5 years striped bass abundance has shown the lowest variability since sampling began.

SPAWNING, MIGRATION AND MOVEMENTS

Spawning Movements

Striped bass are anadromous spawners historically and exhibit strong migrational tendencies in fresh water (Setzler et al. 1980). Mature fish spawn in or below Cataract Canyon, a 19 km-long Colorado River gorge containing 23 major rapids, which is approximately 32 km above Lake Powell's headwaters. Turbulent conditions preferred by spawning striped bass are provided by the series of rapids. No mature adult striped bass have been collected above Cataract Canyon (Persons et al. 1981; Persons and Bulkley 1982). Occasionally, juvenile striped bass which can withstand warmer temperatures have been collected above the rapids during low flow periods in the summer (Valdez 1990). Warm summertime temperatures and high turbidity make year-round striped bass occupation of the river infrequent and unlikely.

Two other major tributaries, San Juan and Escalante Rivers, are small in comparison to the Colorado and spawning striped bass migrations have never been reported. However, there have been occasions when large schools of prespawning adults have been found in the lake headwaters near the inflow of both rivers.

In most years since 1979 there has been a prespawning aggregation of striped bass near Glen Canyon Dam during March, April and May. They were probably attracted to the current created as an average of 20,000 cfs is released from the dam through the penstocks. Large concentrations of striped bass are found each spring at the intake to the Navajo Generating Station which draws water from the lake to the power plant. Mature fish remained near these sources of current for weeks or even months prior to spawning (Gustaveson et al. 1984).

Individual females may hold eggs for months waiting for appropriate environmental spawning triggers. Once triggered, hormone level causes egg deposition to occur in a matter of a few hours. Striped bass river spawning was triggered by a rapid increase in spring runoff from snowmelt. Temperatures from 16-19 C were suitable for spawning when coupled with a surge in flow. Lake spawning was triggered solely by temperature. Hot, calm spring days can cause an increase in surface temperature of 3-4 C in a one day period. Spawning has occurred between mid April and mid June. Schools of mature striped bass staging near the dam left the area, following a rapid warming period when surface temperature neared 20-21 C, to seek out spawning habitat. They preferred points and coves where depth was 1-10 m. Spawning occurs on the surface and usually peaked between 2100 and 2400 h.

Intensive study of the prespawning aggregation of striped bass in 1981 determined that some males ripened by mid-April. All were ripe by May 1st. The main school broke up and left the staging area at the dam during the first week of May before any ripe females were collected. Striped bass in spawning condition were collected on 14 May in a gill net in Warm Creek Bay, 19 km above the dam. The fish were collected in 3-6 m of water near a gradually sloping sandstone talus shoreline composed of sand, cobble, and boulder-sized substrate overlain by 2-3 mm of fine silt.

On May 22, 1982 striped bass were observed spawning in Warm Creek within 1 km of the 1981 collection site. Activity was centered in a large cove over a gradual slope with similar substrate typical of Lake Powell shoreline. Groups of fish spawned on or near the surface from 2300 h until dawn. Dead striped bass eggs were collected in the area the next day. Live eggs were not found and thought to have settled on the substrate (Gustaveson et al. 1984).

In subsequent years, as average size of fish declined collection of mature fish ceased. Many previously mature females suffering the effects of malnutrition had senescent ovaries incapable of emitting viable eggs. From 1985 to 1995 no 4-8 pound females with viable eggs (Bonn et al. 1976) were found. Striped bass females exceeding 10 pounds, though few in number, were healthy and responsible for producing each succeeding annual year class of striped bass. Young ripe males were found every year sometimes in greater abundance than others. Small females less than 4 pounds never developed viable eggs, regardless of age, in the forage-poor era that marked the late 1980's.

The prespawning aggregation of striped bass near the dam persisted despite the lack of sexually mature fish. Spring prespawn staging striped bass have been absent only 3 years out of the last 17. Those absences occurred following threadfin shad population peaks when forage was readily available in uplake locations. Apparently attraction to current in the spring time is an overriding stimulus triggering striped bass migration even when fish are not sexually viable. The only environmental stimulus stronger for most of the population is food availability. When food is available in a specific location, striped bass will spawn in place without extensive migration.

Spawning movements have evolved with subsequent generations of striped bass. The first striped bass were stocked in Wahweap Bay (1974-78). With maturity they returned to Wahweap to spawn as described previously. Subsequent generations seemed to exhibit a more nomadic tendency and have spawned in the backs of many canyons where small flowing streams entered. Spawning now is characterized by location when environmental cues trigger spawning. Spawning can virtually occur anywhere in Lake Powell. The only constant is that relative abundance of yoy is greatest near the inflow and near the dam with fewer yoy found in the mid portions of the lake indicating that striped bass move towards current in the spring.

Prespawning aggregations of striped bass were not detected at Glen Canyon Dam during spring 1996 probably in response to high forage availability in the upper lake during the preceding 18 months. An abundant year-class was produced despite spawning activity being noticeably absent from historically important spawning areas near the dam.

Tagging Study

Striped bass tagged in the early 1980's provided evidence of the nomadic tendencies of the Lake Powell population. From 1981-1987 some 641 striped bass were tagged with Floy anchor (N=394) or cinch-up (N=247) type tags. Tag return was completely voluntary with no reward or other means to entice anglers to submit tags. Some 32 tags (5%) have been returned with the last return in May 1987.

Average duration between tagging and return was 10.75 months. The quickest return was 6 days while the longest known tag retention time was 42 months (Table 6). Average distance traveled between tagging and recapture was 29.4 miles.

Fish tagged from the same school or cohort often exhibited quite different behavior. Fish tagged in the fall, on the same day in Padre Bay (#34,121,123,193), returned the next spring near the prespawning staging area near the dam. One fish (#121) from the group moved uplake indicating that while most fish were drawn to the dam in the spring, some individuals moved to different locations.

Of two fish tagged in Red Canyon in November 1982 (#1289, #1296), one moved to Cedar Canyon. The other fish was recaptured one year later at the same tagging location, but probably after

Table 6. Marking, recapture and movement history of striped bass in Lake Powell, 1981-1990.

Tag No.	Date Tagged	- Location	Date returned	- Location	Distance Traveled - Comment
34	3 Nov 81	West Canyon	17 Apr 82	Dam	35 mi downlake
121	3 Nov 81	Face Canyon	23 Apr 82	Balanced Rock	21 mi uplake
123	3 Nov 81	Face Canyon	28 Oct 82	Dam	25 mi downlake
193	3 Nov 81	Padre Canyon	8 Apr 82	Navajo Canyon	25 mi local
178	2 Oct 81	Wahweap Bay	27 Aug 82	Gunsight Cyn	20 mi uplake
96	20 Sep 81	Navajo Canyon	27 Mar 83	Wahweap Bay	25 mi downlake
1880	30 Oct 82	Last Chance	2 Mar 83	Dam	50 mi downlake
1883	30 Oct 82	Last Chance	21 Feb 83	Dam	50 mi downlake
1894	30 Oct 82	Warm Creek	8 Apr 83	Castle Rock	5 mi local
1896	30 Oct 82	Warm Creek	2 Feb 83	Navajo Cyn	15 mi uplake*Released*
1896*	30 Oct 82	Warm Creek	25 Feb 83	Dam	20 mi downlake
	2 Feb 83	released in Navajo			
1805	31 Oct 82	Last Chance	12 Sep 83	Wahweap Bay	45 mi downlake
1816	31 Oct 82	Wetherill Cyn	Apr 83	Dam	45 mi downlake
1877	31 Oct 82	Wetherill Cyn	21 Apr 83	Warm Creek	35 mi downlake
1815	31 Oct 82	Wetherill Cyn	8 Mar 83	Dam	45 mi downlake
1044	4 Nov 82	Piute Canyon	9 May 86	Navajo Cyn	80 mi downlake
1289	16 Nov 82	Red Canyon	1 Nov 83	Red Canyon	0 return to same site
1296	16 Nov 82	Red Canyon	Jun 83	Cedar Cyn	20 mi downlake
1059	15 Nov 82	Desha Canyon	3 Jun 83	Rincon	15 down then 20 mi uplake
1049	15 Nov 83	Desha Canyon	Oct 85	Escalante	50 mi midlake
1051	15 Nov 83	Desha Canyon	Oct 85	Channel Buoy 72	130 mi midlake
1191	27 Apr 84	Dirty Devil	11 May 84	Dirty Devil	0 Same location
1625	13 May 84	Castle Rock	12 Jul 85	Rock Creek	30 mi uplake
1640	16 may 84	Castle Rock	22 Apr 86	Dam	10 mi local
1226	16 May 84	Castle Rock	11 Feb 86	Dam	10 mi local
1228	16 May 84	Castle Rock	11 Jun 86	NGS intake	15 mi local
1107	15 Jun 84	Hall's Creek	6 Apr 86	Moki Wall	10 mi local
1056	6 Nov 84	Red Canyon	15 Oct 85	Bald Rock	80 mi downlake (10 up SJ)
1054	6 Nov 84	Red Canyon	15 Mar 86	Trachyte	15 mi uplake
1153	15 Dec 85	Halls Creek	28 Sep 86	White Cyn	50 mi uplake
1206	23 Apr 86	Castle Rock	30 May 86	Lake Canyon	90 mi uplake
1086	23 Apr 86	Castle Rock	29 Apr 86	Dam	7 mi local
1155	24 Apr 86	Warm Creek	5 May 87	Wahweap	15 mi local

moving about the reservoir rather than spending the entire year in Red Canyon.

The fish at large for the longest time, #1044, showed movement typical of striped bass. It moved from the San Juan Arm to upper Navajo Canyon where it was recaptured. The journey included 70 miles of travel toward the dam followed by 10 miles of uplake travel to the recapture location. The 80 mile distance between these points could have been retraced many times in 42 months.

The most remarkable fish (#1206 and 1086) were tagged April 23, 1986 at the same time and from the same school (7 miles from the dam). One fish was recaptured 6 days later after joining the prespawning aggregation of fish at the dam. The other fish traveled 90 miles uplake in the space of 5 weeks.

Personal observation combined with tagging studies and sport fish harvest data indicate that striped bass exhibit bipolar migration toward the tributaries and toward the dam in the spring. Prespawning staging occurs as early as March and continues until early June. Spawning occurs in May followed by a dispersal from springtime holding areas. Then striped bass appear to move generally toward midlake in the summer. Fall movement directly relates to forage availability. Random movement of striped bass ceases when abundant forage is found. Striped bass stay with a shad school feeding at the same time each day until the school is consumed, disperses or moves. Random movement resumes as new foraging opportunities are needed. Winter movement appears negligible with fish becoming dormant near where the last foraging opportunity occurred. Spring warming causes a return to the prespawning holding areas near the tributary mouths or the dam.

In years where forage has been plentiful and remains available in the fall, striped bass tend to stay stationary. In Lake Powell, the usual case is that striped bass eliminate most shad from an area and then are forced to move to find more food. The tributary inflow areas are more productive and produce the most shad. In geomorphically dendritic Lake Powell there is a vast distance between forage concentrations in the backs of coves and canyons. With close to 3000 km of shoreline some areas can harbor an unmolested shad population for a short time. Shad peaks in 1991 and 1995 created a lakewide open water shad population with dense numbers close to the tributaries. Striped bass moved to areas of greatest forage density near the tributaries and stayed at those locations rather than migrating downlake in fall. During spring 1992 virtually no striped bass moved to the dam in the spring prespawning period. Apparently forage availability in the upper lake overcame the urge to move downlake. However, by fall 1992, with forage depleted uplake, there was a major downlake migration evidenced by excellent fishing near the dam during winter 1992 and spring 1993.

The same movement occurred in 1995-1996 with two years of high forage concentrations particularly in the upper lake near the tributaries. Striped bass held in the upper lake with no fall movement and no corresponding spring striped bass fishery in the lower lake. But just as occurred in fall 1992, striped bass migrated downlake in fall 1997 after shad numbers declined. Lower lake shad that were not utilized during 1991, 1995 and 1996 were discovered by striped bass the next year and those population were then exploited. Shad are not able to elude striped bass who move constantly in search of food and stay in an area until shad are gone, except in warm turbid shallow water in the extreme backs of the canyons.

SPORT FISHERY

The original striped bass stocked in 1974 did not contribute to the sport fishery until 1979 when 3% of all fish caught in Lake Powell were striped bass. Between 1980 and 1988 striped bass accounted for a significant proportion of all fish caught, peaking at 64% of total harvest in 1985 (Table 7). In the 1991

Table 7. Species composition (%) of total sport fish harvest at Lake Powell, 1964-1997.

YEAR	Largemouth Bass	Smallmouth Bass	Striped Bass	Walleye	Channel Catfish	Bluegill	Crappie	Rainbow Trout	Other
1964	60	-	-	-	9	-	-	25	6
1965	61	-	-	-	7	-	-	27	5
1966	62	-	-	-	8	-	-	27	3
1967	69	-	-	-	20	3	1	5	2
1968	47	-	-	-	21	17	9	1	5
1969	42	-	-	-	11	19	16	10	2
1970	37	-	-	-	8	14	34	4	3
1971	34	-	-	-	4	10	50	1	1
1972-3	29	-	-	-	8	10	50	2	1
1974	37	-	-	-	5	8	48	1	1
1975	48	-	-	-	3	4	44	t	t
1976	42	-	-	-	2	7	47	t	t
1977	32	-	t	t	10	7	49	t	1
1978	38	-	1	t	12	7	40	t	t
1979	48	-	3	2	6	4	36	t	t
1980	29	-	15	10	12	10	24	t	t
1981	39	-	12	10	13	8	18	t	t
1982	26	-	33	9	13	2	16	t	t
1983	19	-	30	7	10	10	23	-	1
1984	34	-	15	8	11	12	18	-	2
1985	10	-	64	10	5	2	7	-	t
1988	9	1	60	3	11	13	1	-	2
1991	10	11	39	2	33	3	1	-	1
1996	11	30	22	1	13	15	8	-	t
1997	5	19	59	3	7	4	3	-	t

\- means no fish harvested
t means less than one percent of harvest

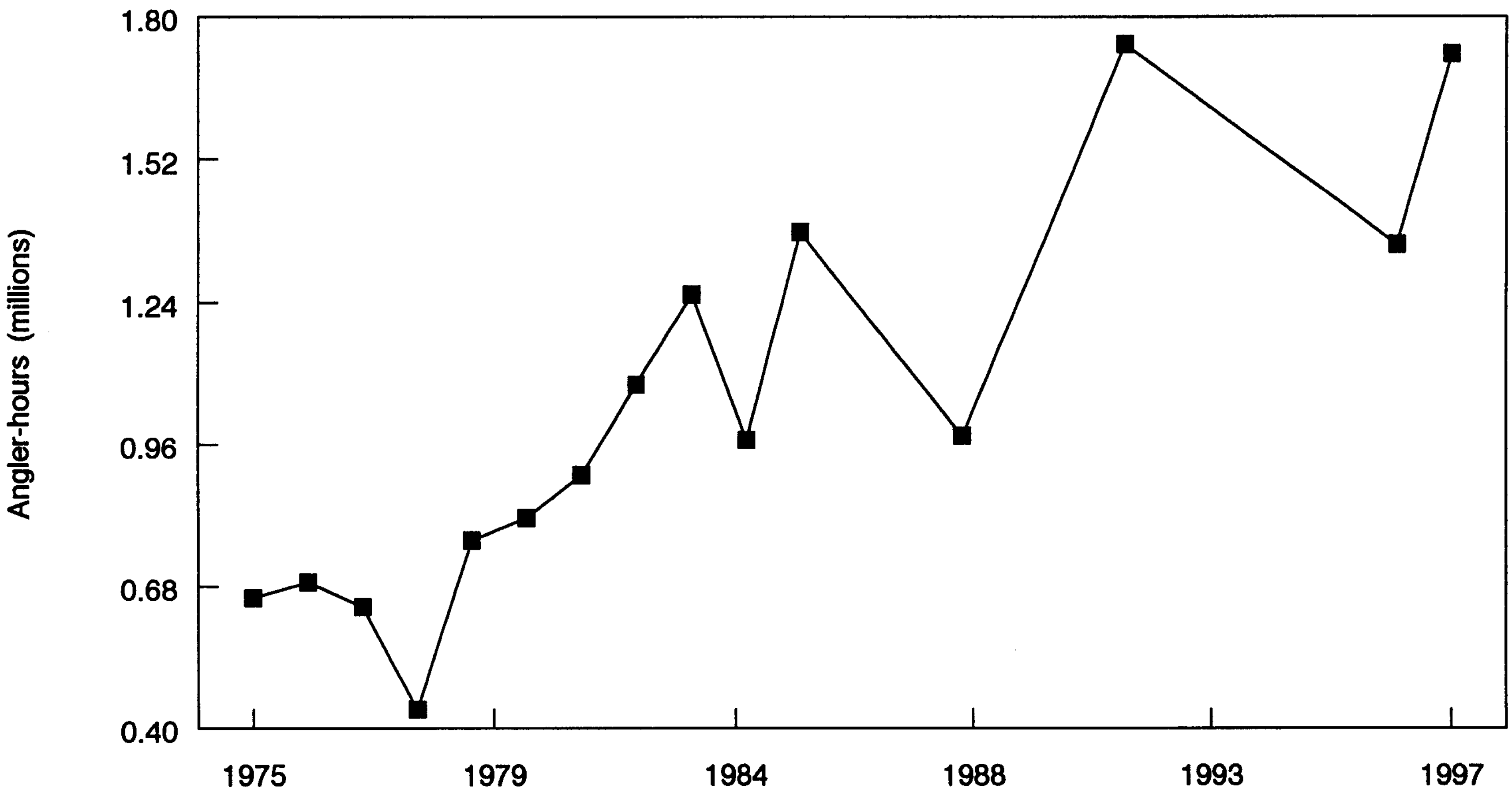
creel census that percentage declined to 39% and dropped to 22% in 1996. In 1997 striped bass harvest rebounded to 59% of total sport fish harvest.

Catchability of striped bass is tied to relative abundance of both striped bass and shad. High striped bass catches generally correlated with low shad abundance. Lack of forage makes angling easier for hungry striped bass. Infrequently, a shad peak, which generally equates with low striped bass abundance, means that forage is plentiful and striped bass are difficult to catch. Lake Powell angling regulations do not allow the use of live bait which has proven to be effective in other waters at times when forage is common. When shad were abundant, cut frozen anchovies which is historically the most common striped bass bait at Lake Powell, proved ineffective.

Angler attitudes were influenced by vulnerability of a particular species to capture. When asked what species anglers wanted to catch they most often responded with a species that had a high catch rate. When striped bass catch rate is up, more anglers said they were pursuing striped bass. Most Lake Powell anglers were generalists who preferred to catch "something" as opposed to specialists who only fish for a certain species (Gustaveson et al. 1998). High striped bass catch rates apparently drew anglers to Lake Powell, probably due to the large size and large number of striped bass that were taken when fishing was good. In contrast, a high smallmouth bass catch rate has proven to be less effective at drawing anglers. Fishing pressure in 1996 was lower than expected despite a record high smallmouth catch, possibly in response to the low striped bass catch rate (Figure 6).

Striped bass are a schooling fish that tend to feed as a group. Feeding activity in one fish triggers a feeding response in other members of the school. Anglers caught fish in bunches when an active school was encountered. After the school departed few striped bass were caught until another striped bass school was located. Hit-and-miss angling characterized the striped bass

Figure 6. Total hours spent fishing on Lake Powell, estimated from creel surveys, 1975-1997.



fishery.

The pelagic nature of striped bass added to the unpredictability of angling for the species. Shad were pursued in open water at random locations making striped bass schools difficult to locate unless shad were chased to the surface creating a surface disturbance or "boil". When striped bass fed deep the use of fish finding graphs enhanced angler interaction with feeding fish. Resting striped bass schools could be detected with the graph and fish stimulated into feeding activity. Presentation of bait at the exact depth of the resting school often induced feeding. Feeding by one fish could get the entire school "started". Chumming was extremely effective in starting feeding activity within a dormant school and has been legalized in Lake Powell to increase harvest of the abundant striped bass population. Only dead anchovies may be used while chumming. Cut pieces of bait were broadcast around the boat. As the bait settled, the resting school was aroused and took all baits in the immediate vicinity for about a few minutes. Chumming was an active part of striped bass fishing. No immediate response meant that there were no agreeable striped bass in the area and the angler had to move to a different location to find an active school.

Striped bass were fairly inactive during winter and early spring until initial warming caused movement to prespawn staging areas. Anglers finding a staging area often caught high numbers of striped bass on cut bait and lures on a recurring basis until the fish left the staging area to spawn. These staging areas were occupied for as long as 3 months in some years.

Both sexes of striped bass will eat while in spawning condition. Spawning congregations could be located with graph recorders, by visual observation of surface disturbance and/or by trolling or casting lures over holding areas. Whether the response was due to aggression or feeding activity is unknown. Most angling success for spawning fish is achieved after dark and in fairly shallow water.

Cessation of spawning causes a renewed interest in food as striped bass become more vulnerable to anglers. Increasing surface temperatures gradually force adult fish deeper toward the preferred temperature zone of 64-68 F. Cooling temperatures in fall allow all sizes of striped bass and shad populations to commingle once again and results in some of the best fishing of the year. The catch rate of striped bass is often highest in the late summer and fall (Figure 7).

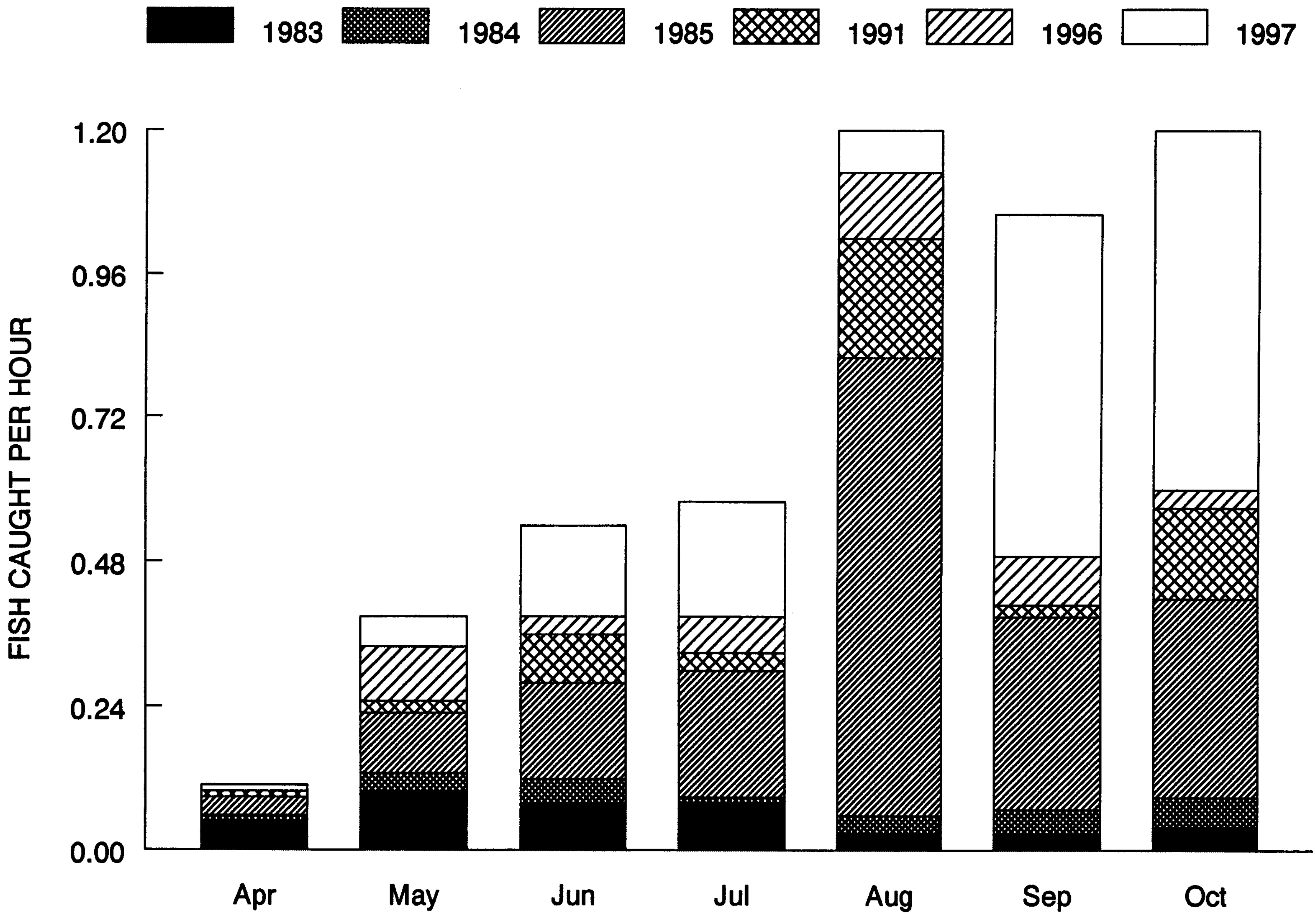
MANAGEMENT STRATEGIES

Forage Introduction

With the discovery of natural reproduction in 1979, plans were made to circumvent potential striped bass over-population. Stocking was immediately curtailed. Creel limits were increased. Unfortunately, striped bass responded more quickly to lack of food than rules could be changed to deal with the problem.

Elimination of shad from the open water in the 1980's and subsequent decline in striped bass condition led to a proposal to increase forage by adding another schooling pelagic forage species (Gustaveson et al. 1990). It was proposed that introducing rainbow smelt (*Osmerus mordax*) would provide a deep water forage fish. The smelt introduction was never made due to objections from other state and federal agencies against any new fish introduction into the Colorado River system. The imperiled nature of remnant populations of endangered Colorado River fishes precluded the smelt introduction because the unknown risk of new species interactions on the remnant fish populations was unacceptable.

Figure 7. Angler harvest of striped bass by month, 1983-1997.



Sport Fish Harvest

Lake Powell has incredible scenery and unique vistas. Millions come every year to enjoy the spectacle. With visitation of this magnitude it seemed possible to actually reduce striped bass numbers by focusing angler pressure on the overabundant population. The initial problem was that most anglers presently embrace a catch-and-release ethic. More than 80% of smallmouth bass caught at Lake Powell are voluntarily released (Blommer and Gustaveson 1997) regardless of limits or other considerations. Anglers do not keep as many fish now as they did in the 1970's and 80's (Gustaveson 1998).

When it was determined in 1990 that it would not be possible to introduce a new forage species an intensive effort was made to educate the public about the need to harvest striped bass at Lake Powell. Anglers are reluctant to embrace a program unless it enhances enjoyment of their sport. Our program included a fishing report aimed at providing the best information available which anglers could use to increase fishing success followed by educational information about the need to harvest striped bass. A toll free fishing information hotline was provided which could be accessed from anywhere in the world offering detailed information on what techniques were working, where fish were biting, and how anglers could enjoy angling success. Reports were updated as new information was received. Much information was gleaned from successful angler interviews even in years when a creel survey was not conducted. That information was disseminated in a timely and credible manner so that anglers could rely on the service.

The hotline was initiated in 1991. It grew from a few hundred phone calls initially to over 30,000 calls in 1995 at which time it became too costly to maintain. It was then combined with the national ASK-FISH fishing hotline service offered by the FWS. The same reports were given but in a recorded operator format which was less user friendly. The report continues today and can be accessed at 1-800-ASK-FISH.

While serious anglers were using the hotline all visitors were not being contacted. The fishing report was printed on letterhead by the Marina concessionaire and made available to every lake user as an information item. The report could be picked up at gas stations, marina stores, and boat rental facilities and many other places where those visiting the lake for other reason may be made aware of the angling opportunities and perhaps include angling in their vacation plans. The report continues to be available at all lake access areas.

Most recently the fishing report has been given wider distribution through the internet on the Lake Powell home page (www.nr.state.ut.us/dwr/lakpowl.htm). More information can be given at the web site about licenses, bag limits, access, fishing forecasts, and many other items. The fishing report is there along with a bulletin board where other anglers can report their success. Anglers can contact us by email with specific questions and receive timely answers to their queries. The program has been successful in providing positive public relations benefits and an increased harvest of striped bass.

Despite these efforts the shad/striped bass populations still cycle. Currently the expected dominance of the 1996 striped bass year class has apparently been neutralized at least in part by anglers harvesting large numbers of striped bass.

SUMMARY AND MANAGEMENT IMPLICATIONS

Striped bass are capable of great growth in Lake Powell when pelagic clupeid forage is adequate. They spawn successfully in the lake without turbulent currents to suspend eggs yet these eggs hatch. The overabundant young fish survive and may exceed the number of shad available as forage. When shad disappear from the pelagic zone due to striped bass predation all striped bass suffer malnutrition. Adult fish eventual starve and are eliminated from the population. Juvenile fish eat zooplankton, grow modestly, and do not gain sexual maturity until shad forage once again becomes available.

Shad survive total elimination by seeking refuge in warm turbid water in the backs of canyons where they are separated from adult striped bass and are not effectively preyed on by sight-feeding juvenile striped bass. Shad produce large numbers of young each year which are usually consumed by juvenile striped bass as they leave the nursery area in search of food. Shad do not recruit to the open water in most years where they would be available to all striped bass. Juvenile striped bass generally have the competitive advantage for food.

In some years either an abundant shad crop is produced or striped bass numbers are small which allows shad to recruit to the open water and provide forage to all striped bass. Abundant shad for one season causes a growth spurt in striped bass. Good shad forage for two consecutive years results in improvement in striped bass size and condition which leads to successful reproduction from the general population, not just a few trophy size fish. Numerous young striped bass produced after two good shad years eventually overcome available shad forage and the cycle repeats itself again.

Striped bass are a tremendous sport fish which draw anglers and create excitement not seen from other Lake Powell fisheries. The trophy size and large numbers can be incredible at times. Striped bass are relatively easy to catch by sport anglers. Fishing is better when fish are overpopulated and malnourished than when shad are abundant.

Striped bass adapt and adjust to ever changing environmental conditions in Lake Powell. With unlimited shad forage, striped bass growth is near the best recorded. But, without pelagic shad forage, striped bass stop growing, stockpile and stunt. The decline is immediately noticeable in declining physical condition and later in lack of ability to reproduce, thereby limiting numbers. Add more forage and growth spurts. Add pelagic shad for two consecutive years and striped bass reproduction occurs.

Management strategies to offset swings in striped bass abundance and condition include the use of angler harvest to reduce total numbers of striped bass and keep that population in balance with available shad forage.

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