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CONTENTS

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A CONSERVATION-ORIENTED CLASSIFICATION SYSTEM FOR THE INLAND WATERS OF CALIFORNIA

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A hierarchical classification system of the inland waters of California is presented, focussing on natural habitats. Its purpose is to provide a structure for conservation efforts and the development of Aquatic Diversity Management Areas. The system is based largely on patterns of fish distribution and endemism but includes fishless habitats as well.

INTRODUCTION

Freshwater environments have been classified in many different ways. Most classification systems are based on the physical and chemical characteristics of water, assuming that aquatic environments with common characteristics in a region have similar biotas (reviews by Hawkes 1975, Wetzel 1983). Other systems have attempted to tie aquatic environments to surrounding terrestrial systems (Hughes and Omernik 1981, Platts 1982, Larsen et al. 1986, Rohm et al. 1987). Recently, various methods of classifying aquatic systems have been developed in order to permit systematic protection of biological diversity in distinct geographic regions (Savage and Rabe 1979, Maitland 1985, O'Keefe et al. 1987, Edwards et al. 1989, Margules et al. 1989). The need for such a conservation-oriented classification system of aquatic environments is particularly acute in California where a rapidly growing human population and large tracts of irrigated agriculture compete with aquatic organisms for water. As a result, California's highly endemic aquatic fauna is in decline, most notably fish (Moyle and Williams 1990).

Protection of aquatic biodiversity in the state requires a state-wide system of Aquatic Diversity Management Areas (ADMAs), streams, lakes, ponds, and springs that are managed with maintenance of native fauna and flora as a primary goal. With limited funds available for ADMAs, it is important to have a classification system of aquatic environments that can help managers decide which environments need protecting in order to maximize protection of biodiversity.

To be useful for conservation of biological diversity, a classification system should:

1) Cover all types of aquatic habitats, especially minimally disturbed natural

habitats.
2) Be easy to use, without being too general or too site-specific.
3) Take into account regional and local endemism of aquatic organisms.
4) Be expandable, so new categories can be added without disrupting data bases that already are using it.
5) Reflect both the physical and biological characteristics of each habitat.
6) Be predictive in that once a site has been classified new users will know what fishes or other organisms are likely to be present.

Ellison (1984) developed a system with many of these characteristics, but it proved difficult to apply to many habitats in California and did not sufficiently account for regional and local endemism. The classification system presented here is basically an expanded and refined version of Ellison (1984). It includes more detailed descriptions of each habitat but excludes marine and estuarine habitats.

METHODS

This classification system is based largely on patterns of fish distribution, because fishes are the best studied aquatic organisms. It assumes that patterns of endemism and distribution in fishes are similar to those of less well-known aquatic organisms and that fish profoundly affect the distribution and abundance of other aquatic organisms. However, its bias towards fish does mean that it should be used cautiously in the development of conservation programs for other groups of aquatic organisms.

The system is organized in a hierarchical fashion, with ichthyological province (Moyle 1976, Moyle and Cech 1988) as the first major subdivider. The ichthyological provinces are also the major drainage basins of California and are equivalent to the "aquatic ecoregions" Hughes et al. (1987) described for Oregon. The five major ichthyological provinces are (1) Sacramento-San Joaquin (including coastal drainages with similar fish faunas to that of the main basin), (2) Klamath and North Coast, (3) Great Basin, (4) Colorado River, and (5) Southern California Coast. The general hierarchical scheme used is:

X0000 ICHTHYOLOGICAL PROVINCE
X1000 STANDING WATERS or X2000 FLOWING WATERS
X2100 **Ephemeral Waters**
(under Standing Waters the numbers would be X1100 etc.)
X2200 **Permanent Waters**
X2210 Fishless streams
X2211 ... X221n Types of fishless streams
X2220 ... X22n0 Types of streams containing fish
X2221 ... X222n Subdivisions of stream types with fish

The final category of the system is Artificial Habitats. These were not included within each geographic category because such habitats differ little between regions. They have unstable water supplies, are usually dominated by introduced fishes (if any), and are largely human made.

The major problem with any classification system like this one is that it places highly variable systems into rigid categories. Users will have to realize that sites with intermediate or changing characteristics may be hard to classify. We suggest that a site with intermediate characteristics be assigned to both of the categories between which the site is intermediate. It is quite likely that the site fluctuates between the two in any case, especially if the site is part of a stream system. A further problem with this classification system is that many aquatic environments today bear little resemblance to what they originally were, and highly disturbed streams or lakes probably cannot be usefully classified unless there is information available on their original flora and fauna. However, the system is flexible, so that new categories can be added without disrupting the structure or original numbering system.

A CLASSIFICATION SYSTEM FOR CALIFORNIA'S INLAND WATERS

A0000 SACRAMENTO-SAN JOAQUIN PROVINCE

A1000 STANDING WATERS

A1100 **Ephemeral Waters**

A1110 Floodplain pool

Shallow pools and ponds left behind on the valley floor by receding floodwaters of Sacramento and San Joaquin Rivers and their major tributaries. Often contain fish early in season but gradually become too warm and deoxygenated for fish. Most dry up by late summer.

A1120 Vernal pool

A1121 Northern claypan pool

Shallow, temporary pools created where winter/spring rainfall fills depressions in claypan soil areas on the valley floor. The alkaline waters contain a rich assemblage of invertebrates adapted for life in temporary pools. Tiger salamander and spadefoot toad larvae may be present in the larger pools. Flowering plants on pool edges highly endemic. Because these pools may fill and dry more than once in a season, they are also referred to as seasonally astatic pools.

A1122 Northeast volcanic vernal pool

Shallow temporary pools on volcanic soils in Modoc County with an endemic flora.

A1130 Playa lake

Large, shallow, alkaline lakes created in valley areas with no outflows to the rivers. A good example is Soda Lake on the Carrizo Plain (San Luis Obispo Co.), whose fauna is dominated by brine shrimp, *Artemia* sp.

A1140 Rock outcrop pool

Pools perched on sandstone outcrops along the western edge of the San Joaquin Valley. They have little or no soil associated with them so flowering plants are few, but they do contain an unusual invertebrate fauna. Examples are found in the Los Vaqueros region of Contra Costa County and in the Joaquin Rocks near Coalinga, Kings County.

A1150 Alpine pool

Clear, oligotrophic pools found in shallow depressions on granitic outcrops at high elevations in which both freezing and drying are limiting factors; seasonally filled with snowmelt or rain water. Support communities of seasonal organisms such as fairy shrimp (*Brachinecta* sp., *Strepotocephalus seali*) and larvae of longtoed salamanders (*Ambystoma macrodactylum*).

A1200 **Permanent Fishless Waters**

A1210 Alpine lakes

Clear, oligotrophic lakes found in cirques and other depressions carved out by glaciers in mountain areas. Historically, virtually all of these lakes were without fish and were dominated by aquatic insects, fairy shrimp and other crustaceans, and the larvae of frogs, principally *Rana muscosa*. Most of these lakes today contain one or more introduced species of salmonid fishes which have altered the native biotic communities considerably.

A1220 Northeast volcanic perennial pools

Isolated pools and lakes created by old lava flows in the Modoc Plateau area, especially in Lassen National Park. Most now contain introduced fishes and original fauna is poorly known.

A1230 Caldera lakes

Lakes and pools occupying the caldera of extinct volcanoes. Examples include Crater Lake (Lassen Co.) and Medicine Lake (Siskiyou Co.). Original biota poorly known; now dominated by introduced fishes.

A1240 Dystrophic ponds/lakes

Shallow alpine waters with boggy edges, presumably in the natural successional process of becoming bogs. Acidic and fishless.

A1250 Saline ponds/lakes

Thurston and Borax lakes are isolated lakes of volcanic origin in the Clear Lake Basin that are too salty to support fish.

A1260 Valley marsh

The floor of the Central Valley once supported extensive tule and cattail marshes that flooded seasonally and were permanently wet. Primarily fishless, but seasonally important for spawning and major habitats for aquatic birds, including migratory waterfowl.

A1270 Northern volcanic pools

Semipermanent, spring-fed shallow lakes that occupy depressions sealed by deposits of volcanic ash or basalt. Home to the fairy shrimp (*Underiella occidental*) and a number of endemic marsh plants. Examples of pools include Boggs Lake, Manning Flat, and Steinharts, Lake County.

A1300 **Permanent Waters with Fish**

A1310 Goose Lake

A large, shallow alkaline lake on the California-Oregon border, Modoc County; home to endemic subspecies of tui chub (*Gila bicolor thallasina*), Sacramento sucker (*Catostomus occidentalis lacusanserinus*), redband trout (*Oncorhynchus mykiss* subsp.), and Pacific lamprey (*Lampetra tridentatus* subsp.), as well as tadpole shrimp (*Lepirurus* sp.).

A1320 Tulare basin lake

Lakes Tulare and Buena Vista were large lakes (now dewatered) that existed on the floor of the San Joaquin Valley which overflowed in wet years into the San Joaquin River. Contained immense populations of native cyprinids (including the now extinct thicktail chub, *G. crassicauda*) and pond turtles (*Clemmys marmorata*). Important habitat for wintering waterfowl.

A1330 Sloughs, oxbow lakes, and backwaters

The Sacramento and San Joaquin Rivers and their major tributaries once meandered over the valley floor creating numerous backwater and floodplain habitats that were important, productive warmwater habitats for native fishes and wildlife. These waters had permanent or seasonal connections to the river. A few sloughs still remain but are highly altered.

A1340 Clear Lake drainage

A1341 Clear Lake

A large, eutrophic, natural lake in Lake County and one of the oldest lakes in North America. Home to Clear Lake splittail (*Pogonichthys ciscoides*), now extinct, Clear Lake tule perch (*Hysterocarpus traski laguna*), and other endemic aquatic organisms.

A1342 Blue Lakes

Upper and Lower Blue Lakes are two lakes created by old landslides damming Cold Creek, a tributary to Scotts Creek which flows into Clear Lake. They contain much the same fauna as Clear Lake, but the fishes are naturally stunted. Upper Blue Lake is deep and clear; Lower Blue Lake is shallow and turbid.

A1350 Big Lake

The large spring-fed lake in Shasta County that drains into the Fall River via the Tule River. Includes Horr Pond and upper Tule River.

A1360 Coastal lagoons

Lagoons at the mouths of coastal streams created by impounding waters by sand bars, e.g., Pescadero Creek Lagoon (San Mateo Co.).

A2000 <u>FLOWING WATERS</u>

A2100 **Ephemeral Streams**

A2110 Alpine snowmelt stream

Small, high gradient streams above the timberline that exist only while snow is melting.

A2120 Conifer forest snowmelt stream

Small intermittent streams in conifer forest areas that also exist primarily while snow is still melting but have flows enhanced by seepage from bogs and meadows. Occasionally important as spawning areas for trout (*Oncorhynchus* spp.).

A2130 Foothill/valley ephemeral stream

Low elevation streams in oak woodland/valley grassland areas that flow primarily in response to winter and spring rainfall, although some water may be semi-permanent in bedrock pools. Have a distinctive succession of invertebrates and may be important spawning areas for Pacific treefrogs (*Hyla regilla*) and newts (*Taricha* spp).

A2200 **Permanent Streams, Goose Lake Drainage**

A2210 Fishless alpine stream
Small high-gradient streams in the Warner Mountains that are too steep or inaccessible to be colonized by native trout. Dominant fauna is aquatic insects.

A2220 Redband trout/lamprey spawning stream
Mid-elevation reaches of larger tributary streams (e.g., Willow and Lassen Creeks, Modoc County) to Goose Lake that contain enough gravel and spring flows to support spawning runs of redband trout and Goose Lake lamprey from the lake.

A2230 Resident redband trout stream
Small tributary streams (including tributaries that form A2220 streams) that support self-sustaining populations of redband trout.

A2240 Goose Lake sucker/speckled dace stream
Lower reaches of tributaries used for spawning by suckers and dace but are frequently dry in summer.

A2250 Valley tui chub stream
Stream reaches with low enough gradients to support Goose Lake tui chubs and other lake fishes. Typically warm and slightly turbid in late summer.

A2300 **Permanent Streams, Pit River Drainage**

A2310 Fishless streams

A2311 Glacial melt stream
Streams that drain melting glaciers on Mt. Shasta. Color is typically a milky brown from "rock flour" created by the grinding action of the glaciers. Biotic diversity low.

A2312 Alpine stream
Most streams above 3000 m elevation in the Sacramento-San Joaquin Basin contained no fish until various salmonids were introduced starting in the late 19th century. Originally dominated by aquatic insects and amphibian larvae.

A2313 Spring stream
Outflows of small springs too small or with too high gradients to be colonized by fish.

A2314 Forest stream
Small streams in forested areas with high gradients.

A2320 Low order trout streams

A2321 Pit River rainbow/redband trout stream
Typically, second, third, or fourth order tributaries to the Pit River with high enough gradients to exclude all fish but rainbow trout.

A2322 McCloud River redband trout stream
The upper McCloud River (above Upper Falls) and tributaries, which are characterized by the endemic McCloud River redband trout (*Oncorhynchus mykiss* subsp.) as the sole native fish.

A2330 Pit River tributaries

A2331 Speckled dace/Pit sculpin stream

Low elevation tributaries to the Pit River characterized by rocky substrates and large populations of speckled dace and Pit sculpin (*Cottus pitensis*). Juveniles of the large cyprinids and catostomids characteristic of A2350 are often found here as well as they may use these streams for spawning. See Moyle and Daniels (1982) for a complete description of this category and A2350-A2380.

A2332 Squawfish/sucker valley stream

The Pit River and the lower reaches of tributary streams (e.g., Ash Creek) in Big Valley, Modoc/Lassen/Shasta Counties. Gradient is low, water muddy and warm; dominant fishes are Sacramento squawfish (*Ptychocheilus grandis*) and Sacramento sucker (*Catostomus occidentalis*).

A2333 Modoc sucker stream

Small, moderate gradient streams in Modoc County containing Modoc sucker (*C. microps*) but dominated numerically by speckled dace.

A2334 Rough sculpin/Shasta crayfish spring stream

Cold, clear, spring waters in lava areas that support a highly endemic fauna, including rough sculpin (*Cottus asperrimus*) and Shasta crayfish (*Pascifasticus fortis*). Biggest examples are Fall River and its spring tributaries and lower Hat Creek.

A2340 Canyon rivers

A2341 Lower Pit River (Hardhead/tule perch river)

The Pit River proper as it flows through its canyon from Pit Falls to its confluence with the Sacramento River. Characterized by deep rocky pools containing hardhead (*Mylopharodon conocephalus*) and tule perch. Deep, swift riffles and runs contain rainbow trout.

A2342 Lower McCloud River

The McCloud River below Lower Falls was a cold, slightly milky river flowing through a deep canyon and characterized by deep pools that housed winter run chinook salmon (*Oncorhynchus tshawystscha*) and bull trout (*Salvelinus confluentus*); both are now extinct in the river.

A2400 Permanent Streams, Central Valley Drainage

A2410 Fishless low-order tributaries

A2411 Alpine stream

Same as A2312

A2412 Forest stream

Second or third order streams in fir, pine, or deciduous forest areas that are too small or too high in gradient to support fish.

A2413 Spring

Springs with constant temperature and flows, fine substrates, and clear water; can support unusual/endemic invertebrates.

A2420 Resident trout stream

A2421 Resident rainbow trout stream
Low order, cold, high gradient streams, dominated by rainbow trout and, often, riffle sculpin.

A2422 Rainbow trout/cyprinid stream
Small streams of moderate gradient supporting rainbow trout and one or two species of cyprinids (mostly California roach, *Lavinia symmetricus*) and/or Sacramento sucker. Example: Upper Putah Creek, Lake County.

A2423 Kern golden trout stream
The upper Kern River (Kern County) and its branches and tributaries that support golden trout (*Oncorhynchus mykiss aquabonita*; *O. m. whitei*; *O. m. gilberti*).

A2430 Salmon-steelhead streams

A2431 Spring chinook stream
Third to fifth order streams at elevations of 500-1500 m with deep canyons containing deep, cold pools that can sustain spring chinook salmon through the summer. Examples: upper San Joaquin River, Fresno County (formerly); Deer and Mill Creeks, Tehama County.

A2332 Steelhead stream
Second to fourth order streams used by steelhead for spawning and dominated by juvenile steelhead. Found primarily in the San Francisco Bay drainage.

A2440 Low elevation streams

A2441 Valley floor river
The main channels of the Sacramento and San Joaquin rivers, plus the lower reaches of their tributaries. Much of the water sluggish in summer and considerable cover is provided by logs etc. from riparian forests. Floods seasonally. Fauna complex mixture of resident deep-bodied fishes, warmwater stream fishes, and anadromous fishes.

A2442 Fall chinook salmon spawning stream
Low elevation, low gradient tributaries to major rivers that dry up in summer but are used for spawning by both anadromous species and resident stream fishes in spring. Example: Thomes Creek, tributary to Sacramento River.

A2443 Hardhead/squawfish stream
Low- to mid-elevation streams characterized by deep, bedrock pools, clear water, and cool temperatures (<25°C); characteristic fishes are hardhead, Sacramento squawfish, and Sacramento sucker, although typically 5-6 species are present.

A2444 Hitch stream
Warm, low-elevation streams with low to moderate current and long reaches with sandy bottoms. Typical fishes are hitch (*Lavinia exilicauda*) and Sacramento blackfish (*Orthodon microlepidotus*), although Sacramento squawfish, Sacramento sucker, and other species may be present. Examples: lower

to middle reaches of Salinas and Pajaro Rivers, Fresno River.

A2445 California roach stream

Small, clear, mid-elevation second, third, or fourth order tributaries that typically contain deep pools in canyons and are often intermittent in flow by late summer. Dominant fish numerically are California roach, but juveniles of Sacramento squawfish and Sacramento sucker are often present.

A2500 **Permanent Streams, Clear Lake Drainage**

A2510 Fishless low order streams

High gradient tributaries to main streams.

A2520 Resident trout stream

Second or third order streams with high enough gradients and cold enough temperatures to exclude all species but rainbow trout.

A2530 Cyprinid/catostomid stream

The middle reaches of the main streams flowing into Clear Lake that are clear and shallow. There are some deep pools that contain California roach, Sacramento squawfish, and Sacramento sucker.

A2540 California roach stream

First and second order intermittent streams that are dominated by California roach.

A2550 Seasonal lakefish spawning stream

The lower reaches of major tributary streams to Clear Lake (e.g., Adobe Creek, Kelsey Creek, Sigler Creek) that usually dry up by midsummer but are important spawning areas for lake fishes (today this means only Clear Lake hitch, *Lavinia exilcauda chi*).

A2600 **Permanent Streams North Central Coastal Drainages**

A2610 Fishless low order streams

First and second order streams either too small or too high in gradient to be used by fishes; typically seasonal in flow.

A2620 Coastal rivers

A2621 Eel River

Characterized by low summer flows and scattered deep pools in a wide canyon and rocky flood plain. Typical fishes are Sacramento sucker and threespine stickleback (*Gasterosteus aculeatus*), although juvenile steelhead may inhabit the deeper, cool water of some pools. Considerably modified in recent years by addition of Sacramento squawfish and California roach. Mainstem Eel River and lower reaches of the Middle Fork Eel, South Fork Eel, and Van Duzen Rivers.

A2622 Russian River

Large coastal river containing hardhead, squawfish, Sacramento sucker, hitch, California roach, and a distinct subspecies of tule perch (*Hysterocarpus traski chi*) as well as anadromous salmonids. Characterized by low summer flows and sudden winter floods.

A2623 Sacramento sucker/roach river

Coastal streams with moderate flows, cool temperatures, and low gradients in their main channels characterized by the presence of Sacramento suckers and/or California roach as well as sculpins *(Cottus* spp.), threespine stickleback, and anadromous salmonids. Examples: Navarro River, Mad River, Matolle River, Bear River.

A2630 Steelhead streams

A2631 Fall steelhead only stream
Small, moderate-to-high gradient streams, often tributaries to larger coastal streams used for spawning by steelhead and characterized by dense populations of young-of-year steelhead and larvae of Pacific giant salamanders.

A2632 Short-run coho stream
Small cold streams with headwaters within 100 km of the ocean. Streams are deeply shaded, with frequent deep (75+ cm) pools which are used by coho salmon (*Oncorhynchus kisutch*) for spawning and nursery areas. Steelhead typically present as well. Example: Waddell Creek, Santa Cruz County.

A2633 California roach/stickleback/steelhead stream
Small, low-to-moderate gradient streams that usually flow directly into salt water. They are dominated by California roach and threespine sticklebacks, but may also contain juvenile steelhead in the faster flowing or more deeply shaded reaches. Examples: Gualala River (Mendocino Co.) and Walker Creek (Marin Co.).

A2634 Summer steelhead stream
Canyon reaches of larger coastal streams and/or tributaries that contain deep (2+ m) bedrock pools capable of sustaining adult summer steelhead through the summer months; summer steelhead and spring chinook salmon are typically the only fish in these streams. Example: Middle Fork, Ee! River (Mendocino Co.).

A2635 Central coast steelhead/speckled dace stream
Small streams flowing directly into the ocean that support speckled dace as well as steelhead. Example: San Luis Obispo Creek.

A2636 Lower Russian River squawfish/sucker tributary
Lower reaches of small tributaries to large coastal streams that support juvenile Sacramento squawfish and/or Sacramento suckers.

A2637 Coastal steelhead/sculpin stream
Small, high gradient coastal streams that have mainly steelhead and sculpins (*Cottus* spp.).

A2640 Chinook salmon spawning streams
Large, seasonal tributaries to larger coastal streams with sufficient gravel beds to be used for spawning by chinook salmon during the fall and winter months; the juvenile salmon move downstream immediately after hatching. Example: Tomki Creek (Mendocino Co.).

B0000 KLAMATH AND NORTH COAST PROVINCE

B1000 STANDING WATERS

B1100 **Ephemeral Waters**

B1110 Dune pond
Small, temporary ponds isolated among or behind coastal dunes.

B1120 Alpine pond
Small, isolated ponds in alpine areas created by snowmelt and rain runoff.

B1130 Sag ponds
Coastal ponds in the Franciscan melange formation that hold water most of the year and are dominated by perennial plants.

B1200 **Permanent Fishless Waters**

B1210 Alpine lakes (see A1210)

B1300 **Permanent Waters with Fish**

B1310 Dune pond
Isolated ponds in dune areas typically covered with water lilies. Examples: Dune ponds in Lake Earl State Park, Del Norte County.

B1320 Coastal lake or lagoon
Permanent lakes created when dunes or sand bars impound streams. May be important nursery areas for anadromous fishes. Example: Lake Earl, Del Norte County.

B1330 Klamath sucker/minnow lake
Large, shallow, productive lakes in the upper Klamath basin containing dense populations of suckers (especially *Chasmistes brevirostris*) and minnows (*Gila* spp.). Examples include Tule Lake and Lower Klamath Lake.

B2000 FLOWING WATERS .

B2100 **Ephemeral Streams**

B2110 Seasonal stormcourse stream
Small, high gradient streams that flow seasonally or in response to heavy local precipitation.

B2120 Seasonal snowmelt stream
Small seasonal streams that drain alpine snow fields.

B2200 **Permanent Fishless Streams**

B2210 Coastal headwater stream
Same as streams in A2610

B2220 Interior headwater stream
First and second order tributaries of interior tributaries to the Klamath, Trinity, and Rogue rivers.

B2300 **Permanent Streams with Fish**

B2310 Resident trout streams

B2311 Redband trout stream
Streams in the upper Klamath Basin, mostly third to fifth order, with cold temperatures and high gradients that exclude most fish except redband trout.

B2312 Rainbow trout stream
Streams or sections of streams above natural barriers in the lower Klamath River and Trinity River drainages that contain populations of rainbow trout derived from steelhead.

B2313 Cutthroat trout stream
Same as B2312, but principal fish present are coastal cutthroat (*Oncorhynchus clarki clarki*); streams typically small.

B2320 Mixed assemblage streams

B2321 Lower Klamath sculpin/dace/sucker stream
Third, fourth, and fifth order tributaries feeding directly into the Klamath and Trinity rivers, with cool (less than 22°C) summer temperatures and moderate gradients, containing rainbow and cutthroat trout, Klamath smallscale suckers (*Catostomus rimiculus*), speckled dace (*Rhinichthys osculus*), and sculpins (*Cottus* spp.).

B2322 Rogue drainage trout/sculpin stream
Third and fourth order streams in the Rogue River drainage containing trout and reticulate sculpin (*C. perplexus*). Example: Applegate River, Elliot Creek (Siskiyou Co.).

B2323 Upper Klamath dace/sculpin stream
Small, third to fifth order streams in the upper Klamath Basin dominated by speckled dace and marbled sculpin (*C. klamathensis*), but often containing trout and juvenile suckers as well.

B2324 Upper Klamath chub/sucker stream
The main Klamath River, the Lost River, and the lower, low gradient reaches of their larger tributaries. Water may be warm in late summer (ca. 25°C) and moderately turbid where it drains large lakes. Dominated by chubs (*Gila* spp.) and large sucker species.

B2325 Klamath Spring stream
Clear, cold streams that originate from large springs in volcanic substrates, usually containing salmonids, sculpins, and speckled dace. Example: Big Springs, Shasta County, tributary to Shasta River.

B2330 Anadromous fish streams

B2331 Eulachon/sturgeon/salmon spawning river
Lower reaches of the Klamath and Trinity rivers, where wide, shallow riffles are used by eulachon (*Thaleichthys pacificus*) for spawning and deep runs and pools are used for spawning by sturgeon (*Acipenser* spp.).

B2332 Fall/winter run chinook river
The main channels of the Klamath and Trinity rivers and major tributaries that are the principal spawning grounds of the fall and winter runs of chinook salmon.

B2333 Spring run chinook/summer steelhead stream
Large tributary streams of the Klamath and Trinity rivers that contain deep pools in canyons which support adult spring run chinook salmon and/or summer steelhead through the summer months.

B2334 Fall/winter run steelhead stream
Small third and fourth order tributaries with cold temperatures, permanent flows, and high gradients which are dominated by

juvenile steelhead and a diverse amphibian fauna.

B2335 Short run coho spawning stream
Small, third to fifth order streams that are important for steelhead but have enough pool habitat to also support juvenile coho salmon. These streams flow directly into the ocean in the Klamath region or flow into the Klamath-Trinity rivers within 100 km of the ocean.

B2336 Cutthroat trout spawning nursery stream
Small, third and fourth order tributaries that are used by coastal cutthroat for spawning and rearing. Often contain sculpins (*Cottus* spp.) and other anadromous salmonids.

B2337 Cutthroat/coho river (Smith River)
The Smith River is an independent coastal drainage that is dominated by salmonids and distinguished by its runs of coho salmon and coastal cutthroat trout. Juveniles of both species are common in tributaries (as are steelhead). The principal predators in the deep pools of the river are large cutthroat trout.

C0000 GREAT BASIN PROVINCE

C1000 <u>STANDING WATERS</u>

C1100 **Ephemeral Waters**

C1110 Alkali playa lake
Shallow lakes in isolated desert basins that dry up annually (except during exceptionally wet years).

C1120 Mountain pool
Shallow pools in alpine meadow areas that either dry up or freeze solid annually.

C1130 Great Basin scrub pool
Pools that form from seasonal rainfall or snowmelt in hardpan areas of the desert and rarely last more than a month or two.

C1140 Rock pool
Natural holes in rocks (often in washes) that fill with water seasonally and may be semipermanent if deep enough. Important sources of water for desert bighorn and other animals.

C1200 **Permanent Fishless Waters**

C1210 Alpine lake/pond
Small, usually isolated, oliogotrophic lakes in high mountain areas formed by the action of glaciers or by cones of volcanos.

C1220 Desert pools and ponds

C1221 Great Basin scrub perennial pool
Small isolated ponds in lowland or sub-alpine areas formed by the damming action of lava flows or landslides and dominated by predatory insects and amphibian larvae.

C1222 Spring pool
Isolated small springs in desert or scrub areas.

C1230 Desert lakes

C1231 Playa lake

Terminal lakes, often large, that occupy desert basins, are too alkaline to support fish life, and may dry up during severe drought periods. Example: upper and lower Alkaline Lakes in Surprise Valley (Modoc Co.).

C1232 Mono Lake

A distinctive, permanent alkaline lake in Mono County with an endemic invertebrate fauna (e.g., *Artemia mona*).

C1233 Owens Lake

A large lake at the terminus of the Owens River that probably was similar in many of its characteristics to Mono Lake (C1232) but now dry due to diversion of inflowing water.

C1300 **Permanent Waters with Fish**

C1310 Alpine Lakes

C1311 Alpine lake/pond

Oligotrophic, permanent alpine lakes with connections to streams with fish. Example: Independence Lake (Sierra and Nevada Cos.).

C1312 Lake Tahoe

A large, deep, extraordinarily clear alpine lake containing a complex fish fauna and unusual deepwater invertebrates.

C1320 Eagle Lake

An alkaline, permanent terminal lake in Lassen County that is productive of fish and fish-eating birds; contains Eagle Lake rainbow trout (*Oncorhynchus mykiss aquilarum*) and tui chubs.

C1330 Honey Lake

A large, shallow, terminal alkaline lake in Lassen County that fluctuates greatly in size, even drying up occasionally, but supports abundant fish life in whatever water it contains.

C1340 Desert Springs

C1341 Lahonton desert spring

Isolated desert springs and associated pools containing fish, usually tui chubs. Example: High Rock Springs, Lassen Co.

C1342 Amargosa desert spring

Spring-fed pools containing Amargosa pupfish (*Cyprindon nevadensis*).

C1343 Owens desert spring

Spring fed pools containing Owens pupfish (*C. radiosus*).

C1350 Desert marshes

C1351 Cottonball Marsh

Marsh on the floor of Death Valley, fed by flood waters from Salt Creek and containing *C. salinus milleri*.

C2000 <u>FLOWING WATERS</u>

C2100 **Ephemeral Streams**

C2110 Alpine snowmelt stream

See A2110

C2120 Conifer forest snowmelt stream

See A2120

C2130 Great Basin scrub snowmelt stream
Small streams flowing seasonally through desert scrub carrying local snowmelt as well as that from higher elevations to permanent streams or terminal lakes.

C2140 Desert wash
Moderate-to-high gradient desert stream courses that mainly carry flood flows from usual rain or snow melting events.

C2200 **Permanent Fishless Streams**

C2210 Alpine streams

C2211 Glacial melt stream
See A2311

C2212 Exposed alpine stream
See A2312

C2213 Spring stream
See A2313

C2214 Conifer forest stream
See A2414

C2220 Desert streams

C2221 Desert scrub stream
Small streams in lowland areas, fed by mountain run-off.

C2222 Mojave desert stream
Small streams in Mohave desert region.

C2223 Amargosa desert stream
Small tributaries to the Amargosa River or other drainages in the Death Valley region.

C2300 **Permanent Streams with Fish**

C2310 Cutthroat trout headwater
Small alpine streams containing Lahontan (*Oncorhynchus clarki henshawi*) or Paiute cutthroat trout (*O. c. seleneris*). Example: By-Day Creek (Mono Co.).

C2320 Cutthroat trout/Paiute sculpin stream
Alpine streams of sufficient size and low enough gradient to contain both cutthroat trout and Paiute sculpin (*Cottus beldingi*).

C2330 Sucker/dace/redside stream

C2331 With cutthroat trout
Coldwater streams containing the typical Lahontan drainage stream fish community (5-6 species, including Lahontan cutthroat trout).

C2332 Without cutthroat trout
Lower gradient reaches of C2231 that are too warm in summer to support cutthroat trout.

C2333 Pine Creek (Lassen Co.)
This is the only large tributary to Eagle Lake and the principal spawning stream of Eagle Lake trout, Tahoe sucker (*Catostomus tahoensis*), and Lahontan redside (*Richardsonius egregius*); it contains a community dominated by the juveniles of these three species, plus speckled dace.

C2340 Speckled dace stream
Small meadow streams, usually spring fed, that contain mainly

speckled dace but occasionally Tahoe suckers and cutthroat trout. Example: Papoose Creek (Lassen Co.).

C2350 Whitefish/cutthroat, trout/sucker stream
Mainstem rivers (e.g., Truckee River, Walker River) and their larger tributaries that contain the complete Lahontan fish fauna including mountain whitefish (*Prosopium williamsoni*) as well as large adults of cutthroat trout and Tahoe sucker. Cutthroat trout now replaced by non-native trout species.

C2360 Tui chub stream
Low gradient streams, usually close to their confluence with lakes, that contain large populations of tui chubs and speckled dace but little else. Examples: Cowhead Lake slough (Modoc Co.); meadow reaches of Willow Creek near Eagle Lake (Lassen Co.).

C2370 Desert streams

C2371 Spring outflow
Outflows of desert springs, usually containing pupfish and speckled dace.

C2372 Amargosa River
Amargosa River, with its distinctive fauna of pupfish and speckled dace.

C2373 Salt Creek
Salt Creek is a saline stream in Death Valley National Monument that contains Salt Creek pupfish (*Cyprinodon salinus*) as its only fish species.

C2374 Owens River
The Owens River and the lower reaches of its tributary streams originally contained an endemic community of Owens tui chub (*Gila bicolor snyderi*), Owens sucker (*Catostomus fumeiventris*), Owens speckled dace, and Owens pupfish (*Cyprinodon radiosus*).

C2375 Mojave River
The Mojave River and tributaries, where Mojave tui chub (*G. b. mohavensis*) once existed.

D0000 COLORADO RIVER PROVINCE

D1000 <u>STANDING WATERS</u>

D1100 **Ephemeral Waters**

D1110 Desert playa lake
See C1110

D1120 Salton Sink
The large playa lake that once existed in the basin now occupied temporarily by the Salton Sea (created ca. 1910).

D1130 Desert intermittent pool
Semipermanent "tanks" with fluctuating water levels that are dominated by invertebrates with desiccation resistant eggs, especially fairy shrimp (Anostraca).

D1140 Colorado River seasonal floodplain lake/pond
Shallow depressions on the flood plain that fill with water during floods but dry up by late summer, so they contain fish only until

conditions become too severe for them.

D1200 **Permanent Fishless Waters**

D1210 Desert spring
See C1213

D1300 **Permanent Waters with Fish**

D1310 Colorado River floodplain lake/pond
Lakes on the Colorado River floodplain created by river meanders and containing a subset of the Colorado River fauna that arrived there in seasonal floodwaters.

D2000 <u>FLOWING WATERS</u>

D2100 **Ephemeral Streams**

D2110 Desert stream
See C2140

D2200 **Permanent Fishless Streams**

D2210 Paiute Creek (desert perennial stream)
The only permanent fishless desert stream in California (San Bernadino County).

D2300 **Permanent Streams with Fish**

D2310 Colorado River

D2311 Main river
Main river channel of the Colorado River, originally with a fauna of endemic big-river fishes and euryhaline invaders from the Gulf of California.

D2312 Sloughs and marshes
Backwaters of the main river that were important nursery areas for native fishes and the presumed home of desert pupfish, *Cyprinodon macularius*.

E0000 SOUTHERN CALIFORNIA COASTAL PROVINCE

E1000 <u>STANDING WATERS</u>

E1100 **Ephemeral Waters**

E1110 Vernal pools

E1111 Southern vernal pool
Temporary pools in basalt areas of the Santa Rosa Plateau, Riverside County.

E1112 San Diego Mesa duripan pool
Temporary pools created by duripan soils and distinctive faunistically from E1113.

E1113 San Diego Mesa claypan pool (see E1112)

E1120 Sag pond
Ponds in depressions created by movement of earth faults, mainly along the San Andreas fault.

E1130 Dune lake/pond
Small lakes and ponds created by sand dunes impounding streams or washes (e.g., Guadalupe Lake).

E1200 **Permanent Waters**

E1210 Perennial playa lake.

E1220 Coastal lagoons.
Lagoons at mouths of streams characterized by tidewater gobies (*Eucyclogobius newberryi*) and other euryhaline fishes.

E2000 FLOWING WATERS

E2100 **Ephemeral Streams**

E2110 Stormcourse stream
Small high gradient streams that flow only in response to heavy rains.

E2200 **Permanent Fishless Streams**

E2210 Island permanent stream
Small, permanent streams on the Channel Islands that have been too isolated to be invaded by freshwater fishes.

E2300 **Permanent Streams with Fish**

E2310 Steelhead spawning stream
Coastal streams with adequate permanent flows of cold water to maintain runs of steelhead; these streams otherwise contain mainly prickly sculpin and threespine stickleback, although arroyo chubs (*Gila orcutti*) and Santa Ana sucker (*Catostomus santaanae*) may be present in some.

E2320 Threespine stickleback stream
Small coastal streams that are too small and warm to support salmonids but will support populations of threespine stickleback, which are often morphologically distinctive.

E2330 Arroyo chub/Santa Ana sucker stream
Warm or cool water streams of the Los Angeles Basin that support the native fish community of arroyo chub, Santa Ana sucker, and speckled dace.

E2340 Resident trout stream
Upper reaches of and tributaries to streams in the region that contain native resident populations of coastal rainbow trout.

F0000 ARTIFICIAL HABITATS

F1000 STANDING WATERS

F1100 **Ephemeral Waters**

F1110 Rice paddies

F1120 Wildlife refuges

F1130 Drainage and evaporation ponds

F1140 Irrigated land

F1200 **Permanent Waters**

F1210 Ponds

F1211 Cold water ponds

F1212 Warm water ponds

F1213 Ornamental ponds

F1220 Reservoirs

F1221 Cold water reservoirs

F1222 Cool water stratified reservoirs

F1223 Warm water reservoirs

F1224 Run-of-river reservoirs

F1225 Forebays

F1230 Flooded pit lakes (gravel and rock quarries, etc.)
F2000 FLOWING WATERS
F2100 **Ephemeral Waters**
F2110 Aqueducts
F2111 Main lines
F2112 Water delivery canals
F2120 Drainage ditches
F2121 Urban
F2122 Agricultural
F2123 Wetland
F2130 Irrigation ditches
F2140 Flood control canals and by-passes

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GONAD MATURITY, INDUCTION OF SPAWNING, LARVAL BREEDING, AND GROWTH IN THE AMERICAN PEARL-OYSTER (*PTERIA STERNA*, GOULD)

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Adult specimens of the American pearl oyster (*Pteria sterna*, Gould) were collected from Bahia de los Angeles, Gulf of California in September 1985. Oysters were brought to spawn after a period of conditioning and after temperature manipulation, were artificially fertilized. Veliger larvae were reared for 32 days at 23.0, 22.5, 18.2, and 17.7°C, but metamorphosis was not achieved. In October 1985 young specimens were transplanted to plastic boxes and their growth was studied *in situ* for a period of 10 months. Their specific growth rate averages 0.10 mm day^{-1} and was positively correlated with ambient water temperature. Thus, specific growth rate was significantly greater ($P < 0.05$) during the warm season.

INTRODUCTION

Human activity has led to the eradication of many species, and can be considered an important selection factor permitting the increase and expansion of some species while other species are depleted as a result of overexploitation. Overexplotation is evident for *Pteria sterna* (Gould) and *Pinctada mazatlanica* (Hanley), two species of pearl-oysters which occur on the west coast of the Americas. Both species are found from the Gulf of California in the north to Peru in the south. Populations of both species have decreased as a result of human exploitation, e.g., pearlfishing (Mosk 1927, Keen 1971, Baqueiro 1984).

Commercial harvesting of these species began around the middle of the 16th century, most of the pearls being shipped to Europe (Vilches 1978). This activity ended in the late 1940s when diminished stocks made exploitation unprofitable. Large piles of *P. sterna* shells could be found along the beaches of the Gulf of California, evidencing the intense activity of pearlfishing industries (Keen 1971). So far, no recuperation of the local populations of these species has been observed.

Despite the potential economic value of these two species, little is known of their biology in contrast to other economically interesting species for which numerous studies have been carried out. The gonad development of *P. mazatlanica* has been studied histologically (Sevilla 1969) and recently, the abundance, distribution, and some aspects of the ecology of *P. mazatlanica* and *P. sterna* have been studied by SCUBA diving in Mexico. *P. maztlanica* is most abundant in shaded and protected shelters between 1.5 and 10-15 m depth, occasionally down to 30 m. *P. sterna* is more sparsely distributed in depth ranges between 3 and 20 m depth (Monteforte and Cariño, in press).

Loosanoff (1945) reported that increasing temperatures stimulated *Ostrea virginica* to gonad maturity. Loosanoff and Davis (1963) developed a method for conditioning several species of bivalves and breeding their larvae. Spawning has been induced in a number of molluscs by rapid changes in water temperature and/or the addition of a suspension of gametes, chemical products, or cultured microalgae at high concentrations (Loosanoff and Davis 1963, Tanaka et al. 1970, Kikuchi and Uki 1974, Breese and Malouff 1975, Morse et al. 1976, 1977, Breese and Robinson 1981, Braley 1985).

Research on the biology of other species of pearl-oysters (Pteriidae) has been reported by Talavera and Faustino (1931), Kawakami (1953), Minaur (1969), Sevilla (1969), Tanaka et al. (1970), and Alagarswami et al. (1983). The present study was the first to be carried out on *P. sterna* and documents conditioning to reproduction and the induction of spawning in adults, fertilization of gametes to obtain larvae, and growth of *P. sterna*.

The aim of this study was to develop a suitable method for reproducing this oyster under laboratory conditions as a means of obtaining spat for recolonization of natural oyster environments, and to culture *P. sterna* for commercial purposes.

METHODS

Study Locality and Collection of Oysters

Oysters were collected from a small bay, Bahia de los Angeles, situated on the west coast of the Gulf of California, lat. 28°57'4'N, long. 113°33'22'W, in September-October 1985. The bay is protected by Angel de la Guarda Island which lies some distance from the shore as well as by numerous small islands (Fig. 1). The bay, which is in an area of extensive upwelling, has free water circulation. The salinity range is 35.4 ± 0.1 g l^{-1} (Barnard and Grady 1968). The water temperature fluctuated from 15.0°C in February to 27.4°C in August.

In September 1985, twenty-three adult individuals of *Pteria sterna*, 11.23 ± 1.55 cm (SD) height, were collected and placed in a 50 l aquarium during the 12-hour journey to the laboratory. The water was maintained at a temperature of between 13 and 17°C by inserting ice bags in the aquarium. The survival rate during the transport was 100%.

Oyster Growth Conditions

Young oysters that had settled around June 1985 (Aguirre-Hinojosa 1987) were collected from Bahia de los Angeles in October 1985. These oysters were distributed

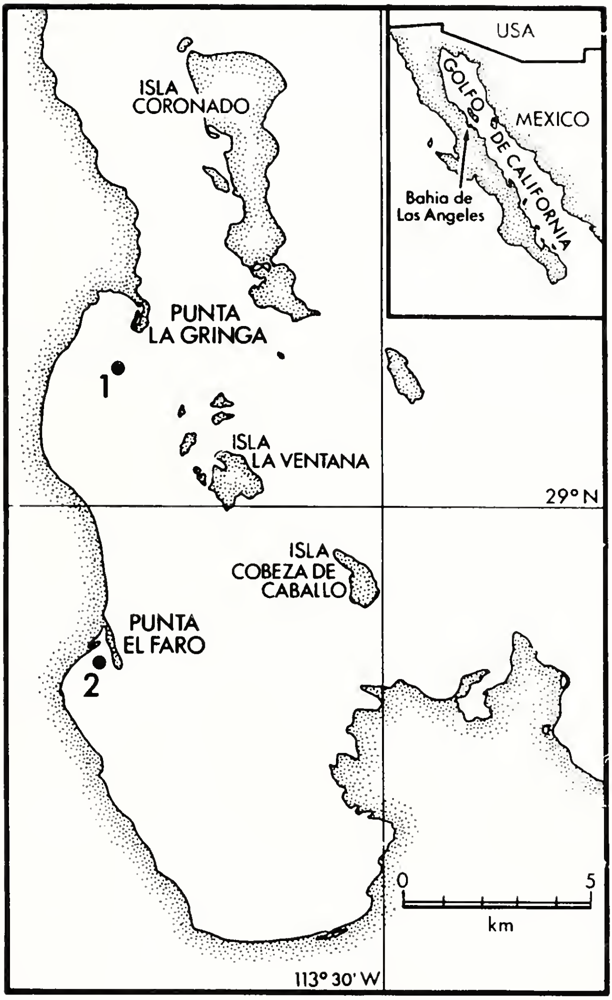

Figure 1. The study locality "Bahia de Los Angeles". Station 1 and 2 are indicated.

in 2 sets of 7 Niester boxes of perforated plastic 60 cm x 60 cm x 9 cm, with 53 individuals in each. The boxes were suspended from a raft at depths between 1.0 and 1.6 m at Station 2 in Punta el Faro and at Station 1 in Punta la Gringa in the south and north of the Bay (Fig. 1). The boxes hung so that each box rested on top of the one below it. Temperature of the surface water was recorded once a month (Fig. 2).

Shell growth was measured along the dorso-ventral axis (DVM) with vernier callipers, from the hinge to the shell margin. This is the normal growth axis of adult pearl-oysters (Alagarswami et al. 1983).

During the measuring procedures, specimens were moved to an aquarium and cleared of epiphytes in order to avoid overestimating of growth rate. To ensure free circulation of water the Niester boxes were also cleared of epiphytes before the oysters were returned to the stations. The boxes were always arranged in the same order, box 1 closest to the surface and in numerical order down to box 7. Growth rate (GR) was analyzed as relative growth. It was calculated as:

$$GR = \Sigma^n (x^a_{t_2} - \bar{x}^a_{t_1})2/n$$

where:

$x^a_{t_2}$ = the height of the oysters in box a at time 2.

$\bar{x}^a_{t_1}$ = the mean height of the oysters in box a at time 1.

The specific growth rate (SGR), was calculated as:

$$SGR = (x^a_{t_2} - \bar{x}^a_{t_1})/T$$

where:

T = the number of days between t_1 and t_2.

To interpret possible dissimilarities in growth rate, the height distribution of the oysters at the beginning and at the end of the observation was analyzed using a one-way ANOVA. ANOVA was also used to determine whether SGR differed during the different seasons. When a significant difference was found the test of homogeneity of the means (Gabriel 1964) was performed.

Microalgal Culture

Three species of microalgae were cultured, *Tetraselmis suecica* Kylin (Prasinophyta), *Pavlova (Monochrysis) lutheri* Green, and *Isochrysis galbana* Parke, (both Haptophyta), using f/2 medium (Guillard and Ryther 1962) and according to the method devised by Paniagua et al. (1986).

Oyster Conditioning to Gonad Maturity

A sample of gonad tissue from each of the oysters to be conditioned was studied under a microscope. Two control oysters were dissected and their gonad tissues inspected. The oysters were divided into two groups. Each group of ten oysters was placed in an 80 l fibreglass, closed-system aquarium with a water flow of 10 ± 1 l per hour. Temperature, pH, dissolved oxygen, and salinity were recorded every two days.

The oysters were fed cultured microalgae. To determine the optimal daily diet ration, values of dry weights of *Tetraselmis suecica*, 292.0 ± 6.7 pg $cell^{-1}$ and *Isochrysis galvana*, 16.1 ± 4.1 pg $cell^{-1}$, according to Romberg and Epifano (1981) were used. The dry weight of *Pavlova (Monochrysis) lutheri* 29.0 ± 3.6 pg $cell^{-1}$ (R.

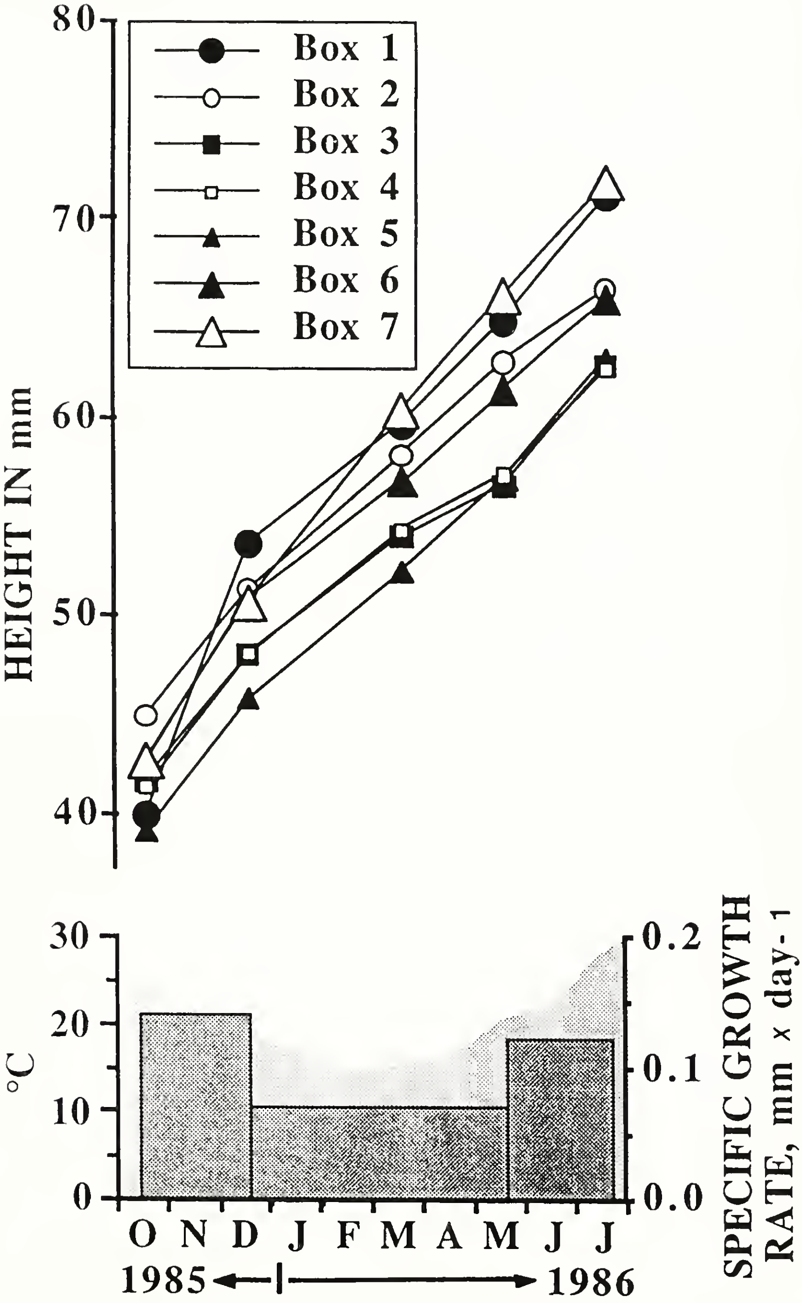

Figure 2. Growth measured as increment of the height (upper graph) and specific growth rates of young oysters, *Pteria sterna*, (bars on lower graph) on a raft in Bahia de los Angeles. Temperature variations are also indicated (shaded area).

Rico C.I.C.E.S.E., pers. comm.). The volumes added of *T. suecica* varied between 0.5 and 1.5 l per day, *I. galvana* between 2.9 and 9.7 l per day and *P. lutheri* between 1.5 and 7.2 l per day, according to the concentrations of the cultures of microalgae, The oysters were fed daily with mixtures of these three cultured microalgae, added in different volumes until they acquired a diet equivalent to 10 mg (dry weight) microalgae ml^{-1} in the 80 l aquarium. This diet was supplied once every day for the first 30 days and twice a day during the subsequent 28 days.

During the first 50 days the temperature varied between 16.4 and 18.2°C and then rose gradually to 24.0°C on day 53. Between day 53 and day 58 the temperature fluctuation was within 23.6 to 26.1°C. One day before spawning induction, the water temperature was lowered to 18.0°C and no further food was supplied to avoid faeces production.

Spawning Induction

The aquarium was cleaned and filled with ultraviolet irradiated, recycled seawater. The oysters were returned to the aquarium and the temperature raised to 24-28°C. Several small aquaria were prepared and kept at the same temperature. The aquaria contained different specimens during the spawning period.

To achieve fertilization, the gametes of 2 females were fertilized with 20 ml of sperm (from at least 2 males) in the small aquaria. After 3 minutes the fertilized eggs were sieved through a 29 μm sieve of nylon plankton net to remove superfluous spermatozoa and placed in a 60 l aquarium at 24°C for 24 hours.

Larval Breeding and Development

After 24 hours the larvae were recovered on a 29 μm mesh sieve and distributed in four 50 l breeding aquaria. A total of 310,000 larvae were placed in aquarium 1, which subsequently achieved a density of 6.2 larvae ml^{-1}. Aquarium 2 held 335,000 larvae with a density of 6.7 larvae ml^{-1}, aquarium 3 held 410,000 larvae with a density of 8.2 larvae ml^{-1} and 345,000 larvae were put in aquarium 4 where density was 6.9 larva ml^{-1}.

Aquaria 1 and 2 were kept at about 23°C with heaters and aquaria 3 and 4 at room temperature, i.e., about 18°C. The breeding aquaria were aerated to maintain high dissolved oxygen levels, water circulation, and to avoid sedimentation.

Table 1. Average environmental parameters in aquaria 1-4 during larval breeding of *P. sterna*.

Aquarium	Temp. (°C)	Salinity ($g\ l^{-1}$)	O_2 dissolved ($mg\ l^{-1}$)	pH
1	23.0±0.7	34.3±2.1	6.6±0.5	7.9
2	22.5±0.6	34.3±2.1	6.6±0.4	7.9
3	18.2±0.3	34.0±1.9	7.2±0.6	7.9
4	17.7±0.4	33.9±1.9	7.3±0.6	7.9

The water was changed every two days. Temperature, pH, dissolved oxygen, and salinity were recorded in each aquarium before the water was changed (Table 1). During water changes, the larvae were siphoned on a sieve of plankton netting of mesh size 29 µm and concentrated in 2 litres of seawater to measure the survival rate. Three samples of 1 ml each were taken from each of the 2 litre stocks of larvae and placed in a glass cell used during microscope counting.

The heights of 25 larvae from each aquarium were measured along their dorso-ventral axis (DVM) to estimate growth. During the last three weeks of the study only eight to ten larvae were measured because of the high mortality. Larvae were preserved in Larval Fixative (Smith and Chanley 1972) for later measurement.

The 24-hour old larvae were transferred to the breeding aquaria and fed a mixed diet of the cultured microalgae *Pavlova (Monochrysis) lutheri* and *Isochrysis galbana.*

As in the adult oyster feeding experiment, the volumes of microalgae fed to the breeding larvae varied by concentration of the microalgae in the culture, determined with a hemacytometer. Mixtures containing 120 to 220 ml of *P. lutheri* and 130 to 440 ml of *I. galbana* were added to each aquarium to obtain a daily diet of 30,000 cells ml^{-1} during the first week. During the second week, two diets, each containing 100 to 190 ml of *P. lutheri* and 120 to 380 ml of *I. galbana*, were added each day to each aquarium to provide a daily diet of 50,000 cells ml^{-1}. From the third week to the end of the larval breeding study, two diets were added every day. The diets contained mixtures of 160 to 290 ml of *P. lutheri* and 700 to 1,400 ml of *I. galbana*, constituting a daily ration of 80,000 cells ml^{-1}.

RESULTS

Specific Growth Rate

Growth rate of young oysters at Station 2 was monitored for four months because the boxes holding the oysters were lost. Thus, only data from Station 1 are presented.

The monthly surface water temperature at Station 1 varied from 15.0°C in February to 27.4°C in August.

The average height of the young oysters ($\bar{x}$) was 41.4±2.0 mm when they were placed in the boxes. The ANOVA showed a significant difference in growth rate ($P < 0.05$) between the oyster groups in the seven boxes. The test of homogeneity of the means showed that the height of the oysters in the second box from the top ($\bar{x}$ = 44.7 mm) was on an average significantly larger than that in the other boxes.

During the first six months significant ($P < 0.05$) differences in relative growth rate between the oysters in the seven boxes were observed. The test of homogeneity of the means revealed that between October and December the oysters in the uppermost box had a significantly greater relative growth rate than those in the other boxes, while from December to March oysters in the deepest situated box had a significantly greater relative growth rate.

The specific growth rate (SGR) was significantly higher ($P < 0.05$) during the warm periods. From October to December 1985, growth was 0.14 mm per day when the temperature of the water changed from 23.9 to 18.7°C. From May to July 1986, the SGR was 0.12 mm per day when the temperature rose from 19.2 to 27.4°C. During the cold season, December to March and March to May, when the temperature of the water was 18.7-15.0°C and 15.0-19.2°C, respectively, the SGR was only 0.07 mm per day (Fig. 2). The overall SGR over these ten months was 0.10 mm per day.

After 10 months the oysters reached an average height of 66.0 ± 3.9 mm. There was a size difference between the oysters in the seven boxes ($P < 0.05$). The oysters in three boxes in the middle were of similar height, with means of 62.4 mm, 62.3 mm and 62.7 mm, respectively, whereas the oysters in the the two uppermost and the two deepest boxes were significantly ($P < 0.05$) larger. The largest oysters were found in the uppermost and the deepest boxes ($\bar{x} = 70.9$ mm and $\bar{x} = 71.6$ mm, respectively).

The survival rate of young specimens of *P. sterna* was high, between 91 and 98%. No predator-drilled oysters were observed. The most abundant epizoans on the oyster shells were sponges, polychaetes, barnacles, bryozoans and algae.

In July 1986, about 13 months after settling, *P. sterna* reached sexual maturity. Field studies revealed spawning at a water temperature of 27.4°C.

Spawning, larval growth and development

A study of gonad tissues showed that *Pteria sterna* is dioecious. Some oysters had small quantities of spermatozoa, while few eggs were found in others. Most of the specimens were in different grades of spent or resting stage, which is normal for bivalves after spawning.

Three successful experiments were conducted to stimulate gonad maturity in *P. sterna* . The oysters produced ripe eggs and active spermatozoa after optimal feeding and significant changes in water temperature. Throughout these experiments other environmental parameters were kept within narrow ranges as follows: pH 7.8 to 8.0, dissolved oxygen 7±1 mg l^{-1} and salinity 33 ± 2 g l^{-1}.

Spawning occurred at temperature fluctuations of between 24.0 and 27.6°C. The oysters spawned from 1.5 to 3 hr of exposure to the spawning temperature. Polyspermy was not observed and the fertilized eggs developed into larvae.

The larvae were kept for 32 days during which only small variations in

Table 2. Shell heights of *Pteria sterna* in four aquaria with two different temperatures (see Table 1). Heights after 1 and 8/9 days were 53.3±4.2 and 72.6±9.2 irrespective of water temperature. Growth rate and developmental stage at the end of experiment are indicated.

Aquarium	Height in µm 17 days	28 days	32 days	Growth rate µm per day	Final development stage in µm
1	83.6±4.1	120.8±16.3	164.2±23.2	5.1	umbo
2	86.1±7.3	127.4±16.3	170.5±26.7	5.3	umbo
3	77.4±3.1	84.6±8.6	108.6±3.9	3.4	prodisoconch II
4	79.2±5.6	92.8±9.5	103.3±5.6	3.6	prodisoconch II

environmental conditions were recorded (Table 1). The early straight-hinge larvae developed after about 24 hours. The height of the shell was on an average 53.3 ± 4.2 µm. They had a smooth, transparent prodisoconch I and swam near the water surface. After 24 hours microalgae were added to each breeding aquarium, as described above.

These planktotrophic larvae developed to prodisoconch stage II. Their shells were less transparent and had concentric striae. After 8 to 9 days from larval hatching the height of the shell had grown on an average to 72.6 ± 9.2 µm.

At day 17 the larvae in aquaria 1 and 2 had grown more than in aquarium 3 and 4. Such differences in growth rate persisted until the study terminated (Table 2). Most of the larvae in aquaria 1 and 2 developed to the umbo stage at day 28 (Fig. 3a).

The study ended on day 32 because of high mortality. Despite the lengthy period over which the larvae were bred, they remained in the umbo stage, in aquaria 1 and 2. The larvae in aquaria 3 and 4 not only grew less, they never reached more than prodisoconch stage II. Several of these individuals developed abnormalities such as a long antero-posterior axis (the axis parallel with the hinge) in relation to the dorso-ventral axis (Fig. 3b). For other individuals the velum was small. These larvae did not live more than a few days.

DISCUSSION

Pteria sterna proved to be tolerant to variations in both temperature and salinity within the ranges used in this study. The oysters cannot however, be transported under dry conditions as can other bivalves (e.g., *Mytilus* and *Modiolus*) which are intertidal species and normally exposed to desiccation at low tide. This was tested

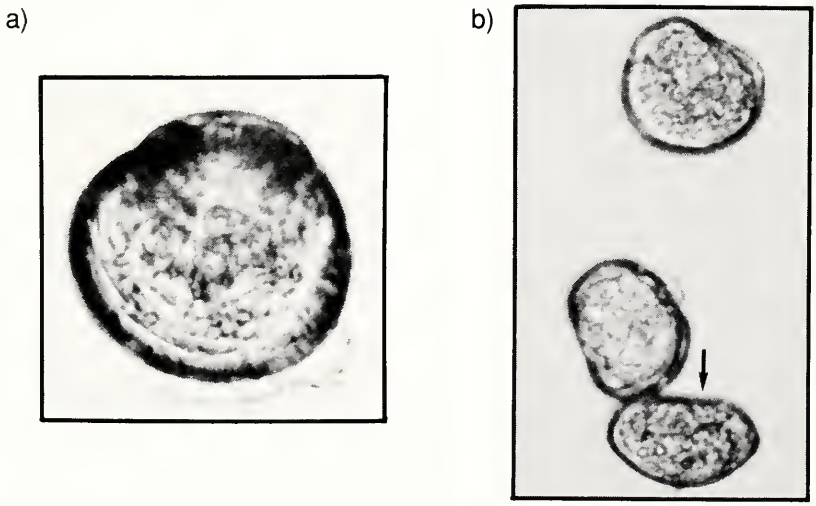

Figure 3. a) *P. sterna* incipient umbo stage 109 µm DVM and b) *P. sterna* veliger larvae, one with an abnormally long antero-posterior axis is arrowed (about 60 µm DVM).

with oysters placed in a box filled with macroalgae but without water. These oysters did not survive for the twelve hours of transport. During our observations in Bahia de los Angeles that covered a period of one year, *P. sterna* was never found on mud flats in the intertidal zone, contrary to Keen's (1971) description of its habitat. Instead, they were observed attached by byssal threads to rocks, stones, live and dead corals, in the shallow subtidal zone. Therefore, we conclude that *P. sterna* has its habitat in the shallow subtidal zone where it lives attached by its byssal threads to hard substrata such as mentioned above and supported by observations by Monteforte and Cariño (in press).

The growth rate of the young oysters was directly related to variations in water temperature. The attenuation of the growth rate in the second warm period seems to be caused by endogenous factors such as the observed thickening of the shell.

The significantly greater average height of the oysters in the topmost and bottommost boxes after ten months may be an indication of competition for food among the oysters. The larger surface exposed to water circulation in these boxes invariably made a greater quantity of food available to the oysters.

The young specimens of *P. sterna* grew approximately as fast as cultured *Mytilus edulis* in Spain, which attain a size of about 50 to 60 mm in 8-10 months. This is the fastest growth rate reported for *M. edulis* in 11 different geographical locations (Loo and Rosenberg 1983).

The growth rate of *P.sterna* was greater than that of *Ostrea chilensis* experimentally cultured in Chile at 30o/ooS. *O. chilensis* grew to 50 mm, the commercial size, within one year post settlement. This is 6-12 months less than the time they need to grow to this size when cultured within their natural distribution range (south of 41°50'S) (Di Salvo and Martinez 1985).

Though *P. sterna* is considered a tropical species, it showed a clear eurythermic reproductive cycle, like the subtropical *Perna perna* (Lunetta 1969, cited in Lubet 1981), the temperate *Cerastoderma glaucum*, *Chlamys varia*, *Crassostrea gigas* (Lubet 1981) and the Baltic *Mytilus edulis* (Kautsky 1982). This may be due to an adaptation to temperature conditions in the Bay, which according to Barnard and Grady (1968) are extreme for a warm-temperate zone.

One problem encountered in this study was the stress of the cultured microalgae. They were added to the conditioning or breeding aquaria, which were several degrees warmer than the aquaria of microalgae culture. The microalgae remained suspended for only a short time before they were sinking thus becoming inaccessible to the oysters or the larvae.

Supporting a laboratory broodstock and obtaining larvae and spat for restocking of the natural local populations requires the production of great quantities of cultured microalgae which is technically difficult and expensive. It is recommended that other feeding regimes be tested, e.g., diets that incorporate other nutritional elements, such as sifted, milled macroalgae. Successful growth and gonad maturity of Japanese pearl-oysters have been obtained with a diet of rice powder (Kuwatani et al. 1974). Laing (1987) reported that the growth of oyster and clam spat fed on a mixture of microencapsulated food and microalgae was similar to the growth rate of oyster and clam spat fed only on microalgae.

Differences in larval growth and development seem to result from differences in temperature. Studies of larval breeding of two other species of the same family, but with tropical and subtropical distributions, showed improved development and growth at higher temperatures. The larvae of *Pinctada maxima* bred at temperatures between 27 and 31°C (Minaur 1969) and the larvae of *Pinctada fucata* bred between 24.3 and 29.8°C (Alagarswami et al. 1983) both developed to the umbo stage after twelve days. In this study *Pteria sterna* developed to umbo stage in 28 days.

During the water change activity it took about 3 hours to raise the temperature to 23°C. This stress factor may also have affected larval growth. A larger range of temperatures should be tested for larval breeding of *Pteria sterna*. Another stress factor in larval development and survival was protozoan contamination induced with the cultured microalgae.

Most stress factors could be eliminated in forthcoming studies. Our results on the fertility of the oysters and the growth rate of the young oysters support our hypothesis that populations of this important resource can be artificially cultured for the purpose of recolonizing natural oyster environments and thus increasing the abundance for commercial purposes.

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HELICOPTER DRIVE-NETTING TECHNIQUES FOR MULE DEER CAPTURE ON GREAT BASIN RANGES

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During the period 1983 to 1989, 304 Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) were captured for migration and home range studies using a helicopter drive-net technique. Two animals died from capture-induced injuries. This paper describes aspects contributing to successful helicopter drivenet captures including net site selection, net configurations, herding, restraint, and handling.

INTRODUCTION

Since 1980, proposals for land developments have increased dramatically in important mule deer habitats on the eastside of the Sierra Nevada, California. This, in addition to a 1975 legislative mandate to develop a management plan for each deer herd in the State, created the need to define the key areas used by eastern Sierra Nevada deer populations. Because radio telemetry can provide objective habitat use information and the reliability of such data increases as the sample size of marked animals increases, California Department of Fish and Game personnel captured over 500 deer for radio-collaring and/or ear tagging in the eastern Sierra between 1983-1989. Methods used include chemical immobilization (Jessup et al. 1983), Clover trapping (Clover 1956), drop-netting (Jessup et al. 1989), and helicopter drive-netting (Beasom et al. 1980). Successful capture of mule deer using the helicopter and drive-net method have been reported by Beasom et al. (1980) and deVos et al. (1984). Silvy et al. (1975) reported capturing Florida Key deer (*Odocoileus virginianus clavium*) with a drive net, and Breland (1984) reported capturing Coues white-tailed deer (*Odocoileus virginianus couesi*) with a helicopter and drive-net. In this paper, we summarized the capture of 304 Rocky Mountain mule deer using this method. Our objective was to describe those factors that contributed to success or failure of captures and to report on techniques from the viewpoint of the helicopter pilot.

METHODS

A Bell 206B Jet Ranger helicopter was used in all our drive-net captures. This make and model of helicopter has adequate power to sustain out-of-ground-effect hover in downwind conditions, and sufficient reserve power for sudden changes in direction of flight and height above terrain while carrying the pilot, an observer, and one and one-half hours of fuel. The helicopter is able to execute maneuvers at the maximum elevations and temperatures in the capture area, in this case up to 7,500 ft and 20°C. In addition, the helicopter was fitted with a cargo hook for captures in remote sites not accessible by ground vehicles. The helicopter was certified for flight with the pilot's door removed to improve the pilot's vision and was supported by fuel truck, sling load equipment, and mechanic-driver with reliable radio communication.

The netting was made by Koring Brothers Co. of Long Beach, California, and was approximately 36-41 cm (14-16 in) stretch mesh size. It was supplied in segments 2.4 m (8 ft) high and 15 m (50 ft) long. Netting was dyed a dull green or brown color to reduce its visibility. When the net was difficult to see from the air, brightly colored net bags or other markers were positioned at the ends of the net to help guide the pilot. Net panels were supported by lightweight poles and each panel was erected independently to prevent several panels being collapsed by a single animal. Adjacent panels were overlapped several feet to preclude gaps which would allow deer to avoid the netting. Nets were erected so that mesh was in contact with the ground, thus preventing deer from going under the panel and providing the opportunity for deer to step into netting on the ground, increasing the chances of entanglement.

Total net size and configuration were determined by terrain, numbers of workers, and other logistical factors including the distance of the net site from a road. Net sets ranged from 50 to 500 m in length.

Net Site Selection

Before each capture, experienced members of the capture team conducted preliminary aerial reconnaissance to determine animal distribution and numbers. An experienced pilot assessed the suitability of the terrain, including the presence of hazards to aircraft, capture crew and animals (Bleich 1983). Over time, we discovered several important criteria for net sites that, in combination, increased capture success. Because much of our work was done in relatively open country with low shrub cover, terrain features were used to conceal the net. Whenever possible, we placed the net in or near a drainage bottom where animals could be herded downhill to the net which was concealed by terrain. We attempted to choose sites where deer could not see the net until they were within 30 m. The final approach to drive deer into the net was at high speed. Whenever possible, the net was placed in a sandy wash bottom, avoiding rocky areas and reducing the chance of injury to animals and handlers. We found it important to place the net in terrain that would allow a downwind approach, thereby reducing the chances of animals detecting the scent of the crew and net. Ideally, a site provided several optional approaches to allow for possible changes in wind direction. These options allowed deer to be driven to the net in such a way that net and crew were not readily visible. Wind direction was crucial and it was difficult or impossible to force deer into the wind toward the net. Once a group of animals had detected the scent of the crew or equipment, a successful capture became more difficult.

We learned to select net sites that provided hiding cover for the workers close to the net, thereby enabling quick access to entangled animals. However, success was lowest in moderate to dense pinyon-juniper habitat where effective herding of animals was difficult. When forced to operate in heavily wooded areas, we had some success by concentrating our efforts on a single animal. Our success improved when our efforts were timed to coincide with spring green-up of herbaceous vegetation (in March) to assure concentrations of animals on lower elevation ranges of moderate topography.

Weather Factors

Ideal weather conditions consisted of a high overcast creating reduced glare and net visibility. A steady breeze of 5-10 knots blowing downwind from the helicopter toward the deer and the net reduced the chance of animals scenting the capture site, while light and variable breezes increased that probability. Winds over 20 knots reduced the margin of safety in this model helicopter because capture operations required downwind hovering at low levels in mountainous terrain subject to sudden changes in wind direction and downdrafts. As reported by Breland (1984), we found the position of the sun to be a consideration. Bright sunlight directly on the net is likely to alert driven animals. Additionally, herding was increasingly difficult when sunlight is in the pilot's eyes because the pilot needed good visibility for instant reaction to animal responses, especially when the animals were close to the net.

Net Configuration

We used net configurations employing angles, 90° corners, "wings", and multiple panels to decrease the opportunity for animals to evade capture. The basic structure often was a wide "H" shape which created a pocket, thereby enclosing herded deer on three sides. Within a given set, certain net sections usually proved most productive, as herded animals often chose the same routes into the net formation. We frequently moved net panels after initial drives to more effectively enclose such favored routes. When a particular configuration was repeatedly successful, double or triple backup net panels placed parallel to it would often result in multiple captures because the additional panels remained standing and functional after the first panels had been collapsed. It was necessary to position these secondary panels 10 m or more apart to prevent their being collapsed by lunging animals that were initially entangled in the first panels.

Net wings (the perpendicular portions of the "H") were particularly important in the capture of additional animals which escaped the initial drive. While it was often impossible to turn an animal back to a net section it had already seen, we frequently turned animals into sections of netting unknown to them. On occasion, the number of animals captured on secondary attempts was greater than that captured on the initial drive because the animals appeared to become very confused, were surrounded by human scent, and therefore could be maneuvered into netting. We learned to cross washes or drainages with netting as terminating a net wing at the edge or middle of a wash frequently resulted in animals escaping down the drainage. At times we moved net sections or wings in response to changes in wind direction, always attempting to maintain the ability to drive the animals in a downwind direction.

Herding Techniques

We used a single observer with the pilot (Breland 1984). The observer must be familiar with the area, deer distribution, and the needs and goals of the project in order to maximize efficiency. Frequent radio communication from helicopter to ground crews was essential and a portable radio repeater was needed in some areas. It was especially important that any changes in wind direction on the ground be made known to the pilot.

We learned a number of successful techniques for moving deer toward and into the net. Distant, careful scrutiny of a large group of deer often revealed the existence of smaller subgroups. We found it easier to herd groups having natural affinity. In some cases, animals could not be coerced into forming a group, forcing us to work with a very small group, a single animal, or abandon the effort. When a maximum sample was desired, we were sometimes able to herd slowly a large group (up to 50 animals) within 1,500 m of the net. The large group was then split into smaller groups for several drives, until the desired sample was obtained. When a small sample was desired from a large group, it was efficient to move the entire group quickly in the initial phase, allowing difficult individuals to escape, retaining those amenable to herding. We usually attempted to bring at least twice the desired number of deer to the net.

When working with a net of average length (about 300 m) and an optimum crew (about 16 persons), we found about six animals to be a manageable number for herding and handling. We herded animals as far as 5 km (3 mi); the key was maintaining adequate distance from the deer so they would move slowly, especially when they were heading in the desired direction. Closer and more forceful herding was required when they strayed from the desired course. Deer were allowed to rest during lengthy drives. Animals moved slowly over long distances appeared no more stressed than those found close to the net and moved immediately at high speed.

At about 200-300 m from the net, close, intense herding was initiated to move the animals the remaining distance at high speed. Moving the animals in a downhill direction on the final approach enabled increased speed and resulted in the animals being committed in the direction of the net and striking it with sufficient force to collapse it on them.

Restraining, Handling

It was frequently possible to drive additional animals back to the net after the initial drive had resulted in one or more deer caught. These secondary drives were successful when one or two people on the ground quickly restrained each animal captured. The balance of the crew remained hidden, awaiting the entanglement of more animals in the remaining netting.

Wherever possible, workers were positioned close to the net and on the side of the net on which deer most likely would approach. Deer striking the net would then have members of the ground crew behind it, effectively causing deer to flee into the net toescape from the crew. If a deer was not fully tangled in the net, a head-on approach by crew members from the other side of the net often resulted in the animal backing out of the netting and escaping. Crew response must be immediate to reduce the opportunity for escape or injury (Breland 1984).

Captured animal's eyes were covered immediately to protect them from foreign matter and to calm the animal. Cautious force should be used for initial restraint until the animal is subdued. Once processing is completed, particular care must be taken by the crew to herd released animals away from any standing net as deer disoriented by restraint and handling may become entangled again and thereby subjected to unwarranted additional stress.

Factors Reducing Success

Experience revealed several factors affecting success. High tree canopy cover was the biggest problem. Thorough reconnaissance of the capture area often revealed optional sites in less dense cover, increasing success. Capture areas should be thoroughly examined from the air and on the ground. For example, at one site we failed to note a short fence at a wildlife guzzler nearby. The subsequent herding operations were severely affected by this unseen barrier.

Often the opportunity for multiple captures was lost due to excessive worker response to the first entangled animals. When only one or two persons restrained each animal, and all other handlers remained hidden, the pilot often was able to herd animals back to the net in a second effort. Conversely, slow or hesitant worker response often permitted entangled animals to free themselves. A few experienced handlers quickly reaching and subduing struggling deer were most likely to succeed in multiple captures on a single drive.

DISCUSSION

Our drive-net techniques have been developed over the past 20 years by numerous California Department of Fish and Game personnel and by pilots Don Landells, Brian Novak, and Steve deJesus, of Landell's Aviation (Desert Hot Springs, California). While several methods are now available for capturing mule deer, and each method has certain advantages, we have found the helicopter drive-net technique to be a very effective and safe method for capturing large numbers of animals in a relatively short time period on Great Basin winter/spring ranges. We found the method to be most appropriate where animals are concentrated in relatively open terrain. Dispersed sampling can be achieved because nets are readily portable.

Selection of particular groups or individual animals is possible.

We found the technique to be advantageous from the standpoint of safety for workers and animals. No human injuries beyond minor cuts and bruises have occurred, and only two deer mortalities have occurred out of 304 captured. However, we recognize the inherent dangers of helicopter operations and it is our opinion that risk management is a distinct and important subject worthy of focused discussion in a separate paper.

The method does have some other disadvantages. When a large number of animals is captured, the cost per animal can be low, but total cost can be high due to the large personnel requirement and the high cost of helicopter time. Our operations during 1988 and 1989 resulted in capture of 123 deer caught using 25.8 hours of flying time for a cost of approximately $84/animal in helicopter time. Krausman et al. (1985) reported costs at $450/animal captured using a net gun fired from a helicopter, excluding per diem, fuel truck costs, and helicopter ferry time. Potvin and Breton (1988) estimated the cost of helicopter time at $423/white-tailed deer caught with a net gun fired from a helicopter. Ishmael and Rongstad (1984) estimated a cost of $523/deer caught with drive nets, Jessup et al. (1982) estimated $390/mountain sheep caught using drive nets, and Beasom et al. (1980) reported a cost of $282/mountain sheep caught in drive nets (cost figures are from Bleich 1990).

We have avoided the use of donated or low-bid helicopter time, recognizing the need for proven equipment and for pilots with extensive experience in animal capture (Bleich 1983).

Inclement weather, especially windy conditions, can hamper or halt the operation. Logistical considerations can impose limitations and increase helicopter costs for transport of netting in habitats lacking road access. Our lowest success has occurred in dense pinyon-juniper cover, while our highest success has been in low shrub or open grassland range where the terrain was used to provide visual cover for the net and workers. Conversely, deVos et al. (1984) reported that drive-net captures in Arizona were best suited to areas of generally dense vegetation.

Each capture effort and site differs in some respects, thereby creating new challenges with each endeavor. All problems cannot be anticipated, but adjustments can be made quickly to compensate for variation.

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HOME RANGE, HABITAT USE, DISTURBANCE, AND MORTALITY OF COLUMBIAN BLACK-TAILED DEER IN MENDOCINO NATIONAL FOREST

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Sixteen female Columbian black-tailed deer (*Odocoileus hemionus columbianus*) were radio-collared in Mendocino National Forest, California. Deer were located or observed from 29 March 1986 to 19 August 1988. Movements and home ranges of deer were classified into three descriptive groups: nonmigratory deer, migratory deer that travelled 3-8 km between summer and winter ranges, and migratory deer that travelled 12-27 km between seasonal ranges. Daytime use of habitats by deer was more than expected in Montane Hardwood and Annual Grassland habitats. Collared deer differed in their individual use of riparian and Montane Hardwood habitats, and used the same areas during fawning each year. Increased vehicular traffic during the hunting season apparently caused displacement of study deer whose usual home ranges during that time of year were within 200m of secondary roads.

INTRODUCTION

There is little detailed information on migratory deer herds of the west slope of California's coast range (Taber and Dasmann 1958). Booth et al. (1982) identified poor regeneration of oak (*Quercus* spp.), poor habitat conditions on the summer range, and lack of vegetative age structure diversity in the shrublands on winter and intermediate ranges as major deer habitat problems affecting this population. Annual adult deer mortality and summer fawn mortality were considered to be high compared to adjacent areas of the Mendocino County (J. W. Booth, CDFG, pers. comm.). This study was conducted to provide some baseline information about habitat use, movements, and mortality factors of deer; and the effects of fire suppression, livestock grazing, hunting, and off-road vehicles on deer.

METHODS

The study area, approximately 38,000 ha in Mendocino, Tehama, and Glenn counties, California, included Mendocino National Forest land and private lands between the east side of Round Valley and the foothills west of Paskenta. Elevations ranged from 366 m along the Middle Fork of the Eel River to 2,270 m at Black Butte. Annual precipitation during the study period ranged from 82-88 cm, approximately

90% of which fell between November and March. Summer temperatures ranged from 10°C to 38°C. During the winter, snow persisted for more than about 1 day only above 1,225 m on south-facing slopes and 760 m on north-facing slopes. The dominant vegetation types in the study area were Mixed Conifer, Montane Hardwood-conifer, Montane Hardwood, Mixed Chaparral, and Annual Grassland (Mayer and Laudenslayer 1988). Common plant species in these types include Douglas-fir (*Pseudotsuga menziesii*) Ponderosa pine (*Pinus ponderosa)* Garry oak (*Quercus garryana*) blue oak (*Q. douglasii*) California black oak (*Q. kelloggii*) scrub oak (*Q. dumosa*) big-leaf maple (*Acer macrophyllum*) Pacific madrone (*Arbutus menziesii*) chamise (*Adenostoma fasciculatum*) manzanita (*Arctostaphylos patula*) and various *Ceanothus* spp. and willows (*Salix*) spp. (Livezey 1988*a*).

Fifteen adult female deer were captured, radio-collared, and ear-tagged on 18 and 19 March 1986 on south-facing hillsides in the Etsel Ridge and Mendocino Pass areas using a helicopter drive-net system. The Mendocino Pass capture sites were 8-11 km north of the Etsel Ridge sites, and the Pony Ridge site was about 17 km northwest of the Mendocino Pass sites. An estimated 95% of the deer in this study area were using the relatively snow-free, south-facing slopes at the time of capture (F. Barney, USFS, pers. comm., J. W. Booth, CDFG, pers. comm.). In addition, one adult female deer was captured using a Cap-Chur dart gun (with Capture-All 5 tranquilizer) near Pony Ridge on 5 May 1987. Deer were collared with mortality mode radio-telemetry collars. Observations of young fawns of collared and uncollared deer were used to estimate times of fawning and breeding, respectively.

Aerial monitoring was conducted from fixed-wing aircraft to locate radio-collared deer 1-2 times per month from March 1986 to March 1988 and less than once per month thereafter. Deer were tracked on the ground using hand-held two-element Yagi antennas (Livezey 1988*b*). Bearings from two to five locations were recorded within 5-15 minutes for each collared deer. Most recorded bearings were taken from roads within 0.5-1.5 km of collared deer. Locations were recorded between 0600 and 0200 hrs (usually between 0800 and 1900 hrs).

Tests of telemetry accuracy were conducted to determine the size of error polygons. Accuracy of aerially-received signals was tested by comparing known signal locations with observed locations. Visual observations of female deer were assumed to be error-free, because these observations were made by finding undisturbed deer typically located in timbered areas. When deer were alerted during before I saw them (3% of the visual observations), then the radio locations were used. Visual sightings usually verified earlier triangulations made 1 min to 1 hr earlier (given the untested assumption that the deer did not move).

Home range areas were estimated by the 100% minimum convex polygon method (Mohr 1947) using Map Overlay and Statistical System (MOSS) software. Locations of group 3 deer (see below) travelling between summer and winter ranges were excluded from home range size estimates. No more than one location per deer per day was used to estimate home range areas or habitat use.

The area analyzed for habitat use included all the area used by 15 Etsel Ridge and Mendocino Pass collared deer. The boundaries were rivers, creeks, and ridges, taking into account physical, "first-order selection" of habitat by the deer (Johnson 1980). Habitat use data were analyzed for the first 2 years of the study (from March 1986 through February 1988). Delineation of the habitat types within this area were reclassified (Mayer and Laudenslayer 1988) from Mendocino National Forest timber strata maps (Livezey 1988*a*). Acreage totals within the vegetation types (availability) were obtained from Mendocino National Forest records. The size and shape of habitat polygons relative to the size and shape of telemetry error polygons was not determined, but the majority of the habitat polygons were larger than the error polygons.

Selection of habitat types by deer was estimated by presenting percent availability, percent use, standard deviation, and range of use. Analysis of habitat use by such statistical tests as X^2 tests and subsequent Bonferroni comparisons, as done by many researchers (e.g., Pierce and Peek 1984, McCorquodale et al. 1986, Ordway and Krausman 1986, Mooty et al. 1987), were deemed inappropriate because these tests assume independence and randomness of observations (Neu et al. 1974, Conover 1980, Hurlbert 1984, Alldredge and Ratti 1986), but individual ungulates show great consistency of use of certain locations and habitats day after day, year after year (e.g., Taber and Dasmann 1958, Bertram and Rempel 1977, Cederlund and Okarma 1988, this study).

RESULTS

Radio-collared deer were located 1,702 times between 20 March 1986 and 19 August 1988: ground-based triangulations (60%), locations determined by signals during flights (28%), ground-based observations (12%), and observations during flights (<1%). Visual confirmation of a deer location was attempted for 9% of the ground triangulations.

Directional accuracy tests of the two-element, hand-held Yagi antenna yielded 90% tolerance limits on degrees of bias at 90% confidence intervals (Kufeld et al. 1987) of -7.44 to 7.44° for the PVC-enclosed antenna (Livezey 1988*b*).

Error polygons of triangulations, using error arcs of -8 to +8°, were 0.01-8 ha for visual attempts (the deer was approached but not seen) and 2-48 ha for all other triangulations. Error polygons of most triangulations were 3.5-32.0 ha. Results of the accuracy tests of aerially-received signals indicated that these locations were ±0.4 km of the true locations. Consequently, error polygons associated with aerially-received signals were about 51 ha.

Home Range and Movements

Movement patterns and home ranges of deer were classified into three groups: 1) resident deer (n=10) that remained in areas other than north-facing slopes (900-1600 m elev.) year-round (mean home range 772 ha) and, during the winter, either remained on their summer ranges or migrated 2.0-8.5 km cross slope or downhill (to 425-550 m elev.), 2) migratory deer (n=3) with summer ranges (mean 293 ha) on

Table 1. Year-round and seasonal home ranges of female Columbian black-tailed deer, Mendocino National Forest, Calif., 1986-88.

Deer group	No. of deer	No. of locations	Mean home range size and range (ha)			Primary aspects used		Elevation range (m)	
			Year-round	Summer	Winter	Summer	Winter	Summer	Winter
Nonmigratory	10	1,141	772 (339-1,914)			SW,W	SW,W	900-1,600	425-1,600
Migratory (3-8 km)	3	284		293 (170-505)	455 (436-475)	N	SW,W	1,100-1,675	800-1,350
Migratory (12-27 km)	3	277		159 (81-250)	502 (353-580)	N,W,E	SW,S,SE	1,100-1,900	675-1,650

densely vegetated north-facing slopes (1,100-1,675 m elev.) and winter ranges (mean 455 ha) on predominently south-facing slopes (800-1,350 m elev) 3-8 km from their summer ranges, and 3) migratory deer (n=3) with summer ranges (mean 159 ha) in densely vegetated areas (1,100-1,900 m elev.) of any aspect and winter ranges (mean 502 ha) on predominently south-facing slopes (675-1,650 m elev.) 12-27 km from their summer ranges (Table 1). All group 2 deer and two of the three group 3 deer shared their winter ranges with group 1 deer.

Habitat Use

Daytime use of vegetation types by collared deer was less than availability except for Montane Hardwood and Annual Grassland habitats (Table 2). Four collared deer (group 1) remained year-round in a valley consisting of Montane Hardwoods and Annual Grasslands interspersed with narrow riparian areas of willows and maples. These deer differed in their individual use of riparian ($\bar{x}$ = 53%, s = 35, range = 7-86%) and hardwood ($\bar{x}$ = 47%, s = 36, range = 14-93%) areas, based on 47 undisturbed, visual observations (Table 3).

Thirteen collared deer that survived at least two or three fawning seasons used their same fawning areas each year. The locations of these fawning areas were estimated to within 10-300 m. Three deer (of 16) fawned in areas that were at least 150 m (range 150-450 m) higher in elevation than the maximum elevation of their ranges during the rest of the year.

Table 2. Daytime habitat use by female Columbian black-tailed deer, Mendocino National Forest, California, 1986-1988.

		Habitat use (n=1,534)		
Habitat[1]	Availability	Mean %	SD	Range
Red fir	4.9	0	--	--
Mixed conifer	25.3	10.0	12.2	0-38
White fir	5.2	0.8	1.9	0-7
Douglas-fir	3.3	0.8	0.8	0-4
Ponderosa pine	7.7	3.0	5.7	0-20
Montane hardwood-conifer	15.2	9.2	11.4	0-41
Montane hardwood	10.4	32.8	12.9	8-58
Black oak	3.0	1.1	2.5	0-9
Mixed chaparral	14.4	2.4	2.7	0-9
Annual grassland	8.9	39.9	19.6	12-74
Total	98.3	100.0	--	--

[1]Habitats were excluded from analysis if they comprised less than 1% of the study area.

Table 3. Daytime use of riparian stringers and Montane Hardwoods by four female Columbian black-tailed deer that remained year-round in the Upper Haynes Creek area of the Mendocino National Forest, California, 1986-1988. Only visual observations of undisturbed deer were included.

	Deer (No. of observations)				
Habitat	336	375	415	425	Total
Riparian stringers	1	12	6	5	24
Montane hardwoods	13	2	2	6	23
Annual grasslands	0	0	0	0	0
Total	14	14	8	11	47

Disturbance During Hunting Season

Traffic on the secondary roads of the study area during the nonhunting season ranged from 0-40 vehicles/day, most of which was due to logging activities and US Forest Service personnel. Smaller roads had less traffic. During the rifle buck-hunting season, vehicle numbers increased to 50-200/day on the secondary roads, and 10-40/day on smaller roads (pers. obs.). Road-hunting was common throughout the study area during the hunting season.

Four collared deer whose usual locations during the summer and fall were 10-200 m from secondary roads were displaced away from roads during the 1987 buck-hunting season (19 September-25 October). The four deer moved 0.6-2.5 km away from their usual areas.

Timing of Fawning and Rutting

Based on observations of young fawns each year, the fawning periods during 1986-1988 began in early June. The peaks of the fawning periods in the study area appeared to be a 2- to 3-week period centered on 21 June 1986, a 2-week period centered on 19 June 1987, and a 2-week period centered on 16 June 1988. Assuming a 203-day gestation period (Taber 1953), these dates estimate the peaks of the rutting seasons as 8, 13 and 10 December for the three successive years.

Mortality

Six of the 16 collared deer died during the course of this 2-1/2 year study, suggesting a 15% annual mortality rate. Three deer were apparently consumed by coyotes, one was eaten by a black bear, one died from bluetongue infection (D. A. Jessup, CDFG, pers. comm.), and one was shot during the hunting season. The causes of death of the deer eaten by coyotes and a bear are unknown.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Seasonal habitat use by collared deer in this study was more aspect-dependent than elevation-dependent. Deer that migrated used more coniferous, timbered areas with more northern aspects in summer and more deciduous-covered areas with more southern aspects in winter, similar to the Columbian black-tailed deer studied by Taber and Dasmann (1958) and Loft et al. (1984). Only tentative conclusions concerning habitat use could be drawn, due to the inaccuracy of the two-element, hand-held Yagi antenna.

The disproportionate daytime use of Montane Hardwoods by collared deer suggests the importance of hardwoods for forage, cover, and/or seclusion. This importance, and the effects of logging operations on hardwoods, were discussed by Loft et al. (1988). The frequent use of grasslands and Montane Hardwoods may indicate the negative effects to deer of fire suppression on the shrublands of California during the past 75 years. Exclusion of fire has permitted the taller growth and resultant unavailability of shrubs to deer, the incapacity of shrubs to compete with conifers, the nutritional decadence of the shrubs, and decreased use of these areas by deer (e.g., Taber and Dasmann 1957, 1958, Salwasser et al. 1978, Kie et al. 1982, Bowyer 1986, Klinger et al. 1989).

Displacement of deer by increased vehicular traffic during the hunting season decreased the amount of land used by deer (Perry and Overly 1977, Rost and Bailey 1979), thereby decreasing habitat effectiveness (Thomas et al. 1979) and possibly increased their energy requirements, territorial interactions, and stress. Closures of some existing roads and eliminating access to drivable off-road areas during the hunting season may reduce displacements and illegal killing of deer by hunters. Traffic was observed to increase dramatically only during hunting seasons during the study period, so it was not possible to determine whether disturbances from activities such as road construction, logging, and other types of recreation cause similar displacements.

The peaks of fawning and rutting estimated for this study are similar to those reported elsewhere in California. Salwasser and Holl (1979) reported a 3-week fawning period centered on 22 June for California mule deer (*O. h. californicus*) in Fresno County. Kie et al. (1984) determined that the peak of the rutting season for two herds of black-tailed deer in Trinity County was 9 December. Knowledge of timing of fawning is necessary to avoid disturbance of fawning deer by activities such as logging and road maintenance.

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HARBOR SEAL PREDATION ON A WOLF-EEL

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Harbor seals (*Phoca vitulina*) usually eat small fishes and invertebrates (Simenstad et al. 1979, Bigg 1981, Riedman 1990). Stomach contents of eight harbor seals from northern California contained predominantly small, bottom-dwelling species of fishes that live on rocky substrate (Jones 1981). Other past and recently collected California material indicate that prey are also often taken over sandy bottoms (J. Harvey, pers. comm.). Intensive observations of harbor seals in central California from 1959 to 1967 indicated that small items were usually consumed beneath the water's surface but larger prey items, such as octopus (*Octopus* spp.) and flatfishes (Pleuronectiformes) were sometimes brought to the surface to be subdued and consumed (J. Vandevere, pers. comm.). One of us (LLR) observed and photographed a harbor seal preying upon an adult wolf-eel (*Anarrhichthys ocellatus*) which may be the longest prey item reported for the harbor seal. On 8 May 1986, at Sand Hill Cove, Point Lobos State Reserve, Monterey County, California, a sub-adult harbor seal surfaced with an adult wolf-eel estimated to be 2 m in length. The struggle continued for 6-12 seconds until the seal bit and removed the wolf-eel's head. A photograph taken at that moment (840 mm lens) showed that copious blood from the decapitated prey had suddenly colored the water red, which further indicated predation rather than scavenging. The seal ate the whitish flesh of the wolf-eel in a sheltered area of the cove, then rested on a rock next to an adult conspecific.

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FIRST RECORD OF PARTIAL AMBICOLORATION IN SPOTTED TURBOT (*PLEURONICHTHYS RITTERI*)

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The spotted turbot (*Pleuronichthys ritteri*, Starks and Morris) is found on the Pacific coast of Baja California, from Magdalena Bay to Point Conceptión (Miller and Lea, 1972). A specimen showing partial ambicoloration was taken in a shrimp trawl at La Bocana, Magdalena Bay (lat. 24° 35' N, long. 112°00' W) on 20 July 1989; water depth was 20 m and surface temperature was 20°C. The specimen was 121 mm standard lenght (153 mm total length) and is catalogued as No. 2196 in the fish collection of the Centro Interdisciplinario de Ciencias Marinas (CICIMAR) in La Paz, Baja California Sur, México.

This fish has the same color pattern on both sides except for an anterodorsal area on the blind side, which is the normal pale color (Fig. 1). In addition, the pectoral fin on the blind side is the same size as its partner, whereas in normal fishes of spotted turbot is much smaller.

The bibliographies of Dawson (1964, 1966, 1971) and Dawson and Heal (1976) document 1,498 cases of anomalies in fishes, of which 102 involve ambicoloration,

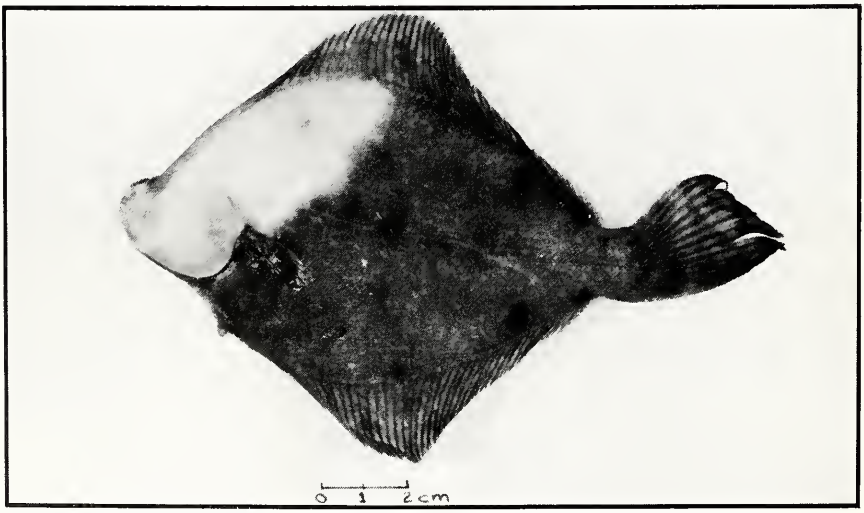

Figure 1. Blind side of partially ambicolored spotted turbot (*Pleuronichthys ritteri*).

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among which four species of *Pleuronichthys* are included (*P. cornutus*, *P. coenosus*, *P. decurrens*, and *P. verticalis*). Thus, the Magdalena Bay specimen is the first record for *P. ritteri*.

Norman (1934) cited numerous cases of albinism, ambicoloration and associated abnormalities in flatfishes and the phenomenon is certainly not rare. Dawson (1962), who recorded five more North American anomalies, was not satisfied with current theories and called for further studies to decide if such anomalies result from mutations or from exogenous factors prior to metamorphosis. He found a higher incidence of such anomalies in fishes from colder waters and that specimens showed as much albinism as reverse scalation, thus the origin was probably in the early larval stages. Love and Vucci (1973) carried out an experiment with partially ambicolored flatfishes to see the effect on color changes, feeding and swimming, but without positive results. Haaker (1973) and Haaker and Lane (1973), documented seven species of flatfishes with total or partial ambicoloration and believed that the interaction between exogenous and genetic factors was perhaps responsible for controlling abnormalities in flatfishes, including ambicoloration. Almost certainly the resolution to this problem lies in experimental work.

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NEW DIRECTOR FOR CALIFORNIA DEPARTMENT OF FISH AND GAME

Governor Pete Wilson named Boyd H. Gibbons as Director for the Department of Fish and Game on December 11, 1991. A Los Angeles native, Gibbons served on the senior editorial staff of National Geographic magazine since 1976. He is the author of many articles such as "The Itch to Move West" about the Oregon Trail and "A Durable Scale of Values" which is a profile of Aldo Leopold, the father of game management.

From 1974-76, Gibbons served as a senior research associate with Resources for the Future, a non-profit organization in Washington, D.C. dedicated to policy research on natural resources.

An attorney, Gibbons held several significant positions in the federal government. He was Secretary for the first Council on Environmental Quality (CEQ) in the Nixon Administration, where he worked on issues ranging from land use policy to wetlands protection.

From 1969-70, Gibbons served as Deputy Undersecretary of the Interior, and was, from 1967-69, a Legislative Assistant to Republican Senator Paul Fannin of Arizona.

Gibbons is a graduate of the University of Arizona (1959) and its College of Law (1962). From 1962-65, he served as a Judge Advocate in the U.S. Air Force in Okinawa, and later practiced law in Phoenix. He is member of both the Arizona and California Bar Associations.

PETE BONTADELLI NAMED TO OIL SPILL POST

The Governor also appointed former Director Pete Bontadelli as Administrator of the Department's recently established Oil Spill Prevention and Response Program. Bontadelli will also serve as Chief Deputy Director of the Department. The Governor praised Bontadelli's efforts as Director: "Pete's done a terrific job as Director of Fish and Game, and I'm very pleased he will be leading this new and important program for the State." The new program will be responsible for coordination and directing the State's response to midland and offshore oil spills, and will operate on an annual budget of about $15 million.

Both Bontadelli's and Gibbon's positions are subject to Senate confirmation.-*Excerpted from Governor's Office Press Release, December 11, 1991.*

MISCELLANEA

The following letter was received along with a marking band by the Department of Fish and Game on 18 September 1973:

> *Gentlemen:* In returning the enclosed, I am reporting that one of your banded, dumb pigeons impersonated a dove in the early morning of Sept. 1st, 1973, at 110th and G streets, 10 miles west of Lancaster. It was shot dead for this act of deceit. *Sincerely yours, Anon.*

On July 11, 1916, while on a trip to Rae Lakes, when about five miles by trail from the new Inyo Hatchery and about one and a half miles from Oak Creek Pass, Mr. F. Shebley, Mr. C. Walters, and myself, saw 22 mountain sheep (*Ovis canadensis sierra*).- *E.H. Ober, Volume 2(4) October 1916.*

Game Wardens and Automobiles- Under a new ruling by the State Board of Control deputies of the Fish and Game Commission who own automobiles are to receive a flat rate of 4 cents per mile while the automobiles are being used in the service of the State... The State recognizes the increased efficiency of the deputy who uses an automobile and this new ruling, although perhaps not as liberal as it should be, is a step in the right direction.- *Dr. H.C. Bryant (ed.),Volume 2(2) April 1916.*

The Conservation of Native Fauna- The October number of *The Scientific Monthly* contains an interesting article entitled "The conservation of native fauna," by Walter P. Taylor of the Museum of Vertebrate Zoology, University of California... The concluding paragraphs of Dr. Taylor's paper point out the fact that not only California, but the whole world, has been wasteful of its wild life resources for the last fifty years, and that it is vitally important that the people everywhere understand the urgent necessity for conservation measures even more rigid than those already in force...On the biologist is laid the role of leadership in the campaign for the preservation of native fauna and on him must blame for ignorant and destructive popular action, legislative or otherwise, inevitably fall.- *Philip Janney, Volume 3(2) April 1917.* (Not much has changed?- *E.R. Loft, 1991*).

Sea Otters Near Catalina Island- On March 16, 1916, 31 sea otters, two being young ones, were seen to the south of Catalina Island. Although one has occasionally been seen in this locality before, this was the largest number, to my knowledge, counted at one time.- *Geo. Farnsworth, Volume 3(2) April 1917.*

Valuable Information for Albacore Industry- The investigations on the albacore industry instituted by the Fish and Game Commission are bearing fruit. In this number of California Fish and Game (page 153) Mr. Will F. Thompson points out that there is a correlation between the catch of albacore and the temperature. It is needless to state that if this point can be substantiated albacore fishermen will have the information they have desired for so long. The ability to predict the catch and dependable information on the location of the albacore at all times of the year seems an immediate possibility.- *Dr. H.C. Bryant (ed.), Volume 3(4) 1917.*

INDEX TO VOLUME 77(1991)

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EDITORIAL POLICY

California Fish and Game is a technical, professional, and educational journal devoted to the conservation and understanding of fish, wildlife, and native communities. Original manuscripts submitted for consideration should deal with California flora or fauna, or provide information of direct interest and benefit to California researchers and managers.

MANUSCRIPTS: Refer to the CBE Style Manual (5th Edition) and a recent issue of *California Fish and Game* for general guidance in preparing manuscripts. Specific guidelines are available from the Editor in Chief.

COPY: Use good quality 215 x 280 mm (8.5 x 11 in.) paper. Double-space throughout with 3-cm margins. Do not hyphenate at the right margin, or right-justify text. Authors should submit three good copies of their manuscript, including tables and figures to the Editor in Chief. If written on a micro-computer, a 5.25 or 3.5 in. diskette of the manuscript in word processor and ASCII file format will be desired with the final accepted version of the manuscript.

CITATIONS: All citations should follow the name-and-year system. See a recent issue of *California Fish and Game* for format of citations and Literature Cited. Use initials for given names in Literature Cited.

ABSTRACTS: Every article, except notes, must be introduced by an abstract. Abstracts should be about 1 typed line per typed page of text. In one paragraph describe the problem studied, most important findings, and their implications.

TABLES: Start each table on a separate page and double-space throughout. Identify footnotes with roman letters.

FIGURES: Consider proportions of figures in relation to the page size of *California Fish and Game.* Figures and line-drawings should be of high-quality with clear, well-defined lines and lettering. Lettering style should be the same throughout. The original or copy of each figure submitted must be no larger than 215 x 280 mm (8.5 x 11 in.). Figures must be readable when reduced to finished size. The usable printed page is 117 x 191 mm (4.6 x 7.5 in.). Figures, including captions cannot exceed these limits. Photographs of high-quality with strong contrasts are accepted and should be submitted on glossy paper. Type figure captions on a separate page, not on the figure page. On the back and top of each figure or photograph, lightly write the figure number and senior author's last name.

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