Increasing Australian impoundment fisheries potential

Habitat enhancement to improve angling and productivity in impoundments

Winston Churchill Fellowship Report

Andrew Norris

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Report by - Andrew Norris - 2015 Churchill Fellow.

To investigate strategies for increasing Australian impoundment fisheries productivity and improving recreational angling and regional economic growth

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Signed Andrew Norris Dated 28/01/2016

Contents

Glossary

AGF	Arizona Game and Fish
AU	Anglers United
BLM	US Bureau of Land Management
BOR	US Bureau of Reclamation
CDFW	California Department of Fish and Wildlife
Environmental engineering	Modifying the physical and biological characteristics of a reservoir to make them more suitable to fish productivity and angling
Fingerling	A small juvenile fish
Fisheries productivity	The number of fish that can be produced or sustained within a waterway
Macrophyte	An aquatic plant
MDC	Missouri Department of Conservation
NCWRC	North Carolina Wildlife Resources Commission
NGP	Nebraska Game and Parks
ODWC	Oklahoma Department of Wildlife Conservation
Recruitment	Survival of fish until maturity or size they can legally be kept
Reservoir or impoundment	Artificial body of water created by building a dam across a waterway
RFHP	Reservoir Fisheries Habitat Partnership
TPWD	Texas Parks and Wildlife Department
UDWR	Utah Division of Wildlife Resources
UNL	University of Nebraska - Lincoln

Introduction

Recreational angling is an extremely popular pastime in Australia and generates significant social and economic benefits, particularly in regional areas. It has been estimated the economic value of individual reservoir fisheries can be up to $10.42 million per year in Australia (Gregg & Rolfe 2013). Much of this value is generated from visiting tourists coming to fish the reservoir, injecting essential money into local communities. Given the popularity of reservoir fisheries in Australia, any decline in angler expenditure could have significant detrimental impacts on regional economies. However, there is also great potential to increase the benefits to nearby communities by improving the reservoir's fishery. A study in central Queensland found that improving catch rates by 20% per annum at several Queensland reservoirs would lead to estimated increases of impoundments values of between $0.12 million and $0.39 million per impoundment per year (Rolfe & Prayaga 2007).

One of the major challenges facing reservoir fisheries is the decline in reservoir productivity and habitat due to the natural effects of reservoir aging. In Australia reservoirs construction was abundant in the mid to late 1900's. Some of these impoundments are now more than 40 years old and the impacts of aging are starting to have significant impacts on their fisheries. The impoundments were built for flood mitigation, town water supply, irrigation or to capture water to generate hydroelectric power, but often with little regard towards fisheries. In many cases the habitat was cleared prior to the initial flooding of a reservoir, leaving limited structural complexity.

The availability of habitat is an essential requirement for fish to accomplish daily and seasonal survival tasks such as foraging, sheltering and reproducing. The habitat in many impoundments has declined greatly as they have aged. Habitat that was present during the initial filling has deteriorated and so have the associated fisheries. Reservoirs age at a much greater rate than natural lakes; however active management through habitat enhancement has the potential to slow or reverse this decline. When an impoundment fishery declines, generally so does the number of anglers using the impoundment and the benefits they bring. As Australia's population grows, more pressure will be placed upon these fisheries and early intervention is the most cost effective strategy to develop and maintain sustainable fisheries.

Habitat enhancement has been practiced around the world for thousands of years. Artisanal fishers once placed structures in waterways to attract fish. Habitat enhancement to improve fisheries is still commonly practised around the world today, particularly in marine environment. Some enhancement and restoration work has also been undertaken in freshwater systems, but this has mostly focussed on habitat in rivers and streams. Fisheries habitat enhancement has less commonly been undertaken in reservoirs and lakes. Unfortunately lake and reservoir habitat has generally been poorly documented. Many of the reports that have been written, exist in the grey literature and are not readily available to the general public. Research and knowledge on structural enhancement of impoundments to improve fisheries is in its infancy in Australia, but many lessons can be learned from overseas.

The USA is the world leader in the field of reservoir fisheries habitat restoration and has the most detailed documentation of projects. Reservoir habitat enhancement has been occurring for more than 30 years in the USA to counter declining fisheries from reservoir degradation and is utilised in some form by almost all USA state fisheries agencies (Tugend *et al.* 2002). Different strategies have been used in different states and across a wide range of scenarios. Some states focus on fish attraction whilst others aim to increase the productivity in a reservoir. Both approaches have the potential for large-scale benefits to anglers and can be undertaken independently or in conjunction with each other. In Australia many impoundments were built more recently than those in the USA (in the 1960-1980s) and what has been observed in US reservoirs is starting to be repeated in Australia. Therefore what occurs in the older USA reservoirs and how the issues have been overcome is extremely valuable to Australia and provides the opportunity to save precious time and resources and develop best practice for our own waterways before the problems become too large.

"When the situation was manageable it was neglected, and now that it is thoroughly out of hand we apply too late the remedies which might then have affected a cure." *Winston Churchill 1935*

Freshwater fisheries in Australia and the USA share many similarities. Recreational angling is an extremely popular past-time in both nations, but the scale of the recreational fisheries is far greater in the USA. It is estimated more than 24.2 million people go fishing in a reservoir at least once a year in the USA (USDI *et al.* 2012and generates a national economic value of $24 billion per year. Although recreational angling is also extremely popular in Australia, far fewer people participate each year and the economic benefit is currently significantly less.

Many of the recreational reservoirs fisheries in the USA share similar characteristics to those in Australia. The states visited during my Churchill Fellowship in the USA all have important warm-water fisheries and experience climatic conditions similar to many parts of Australia. Although the actual fish species differ between the nations, many of them occupy similar ecological niches and provide similar ecosystem services. The habitat enhancement principles that have been successfully applied in USA reservoirs should therefore be applicable to Australia as well.

One of the key differences between reservoir fisheries in the USA and Australia is the reliance on stocking to sustain populations. Many USA sports fish species readily spawn in reservoirs and lakes and maintain self-sustaining populations. Improving the availability of suitable spawning habitat can lead to significant improvements to the fisheries. However, in Australia most recreationally important fish species do not spawn or spawn poorly in reservoirs. The enhancement of impoundment fisheries has largely been based on restocking and far less attention is given to improving habitat necessary for natural recruitment. Reliance on stocking shifts the management focus in Australia towards survival of stocked fingerlings (equivalent to recruitment), growth rates and carrying capacity. As Australia's population grows and access to rivers becomes more difficult, greater emphasis will need to be placed on directing fishing pressure towards impounded waterways and greater effort placed into managing dam, lake and reservoir fisheries to counter the additional fishing pressure. Habitat enhancement is a key tool to making this strategy effective and sustainable, whilst also reducing pressure on wild river fish populations.

Water levels in many USA reservoirs are very stable. The reservoirs have reliable incoming flows from rivers and often other reservoirs upstream regulate inflow rates and water levels. Many of the reservoirs serve hydro-electric power generation stations and as water storage for irrigators. This results in consistent water releases, and combined with large, shallow reservoirs, aid stable water levels. In Australia, reservoirs serve similar purposes to those in the USA, but have more ephemeral catchments, less regular inflows and in places, a greater proportional discharge for irrigation supply. This can lead to highly variable water levels in these impoundments and introduces a range of issues for habitat enhancement that are not as prevalent in the USA. Habitat enhancement can be successfully implemented under highly variable water level fluctuations, but requires more forethought and planning. USA fisheries biologists and reservoir managers are also working to overcome this management challenge.

The goal of my Churchill Fellowship has been to summarise current best practice for reservoir habitat enhancement in the USA and develop a series of recommendations to improve reservoir fisheries in Australia. Much of the information in this report was based on reports, documents and images made available by the USA partner agencies I visited. Accessing many of these documents is difficult, so to make the information more readily available to Australian fisheries managers and stakeholders, I have included descriptions of the various reservoir habitat enhancement techniques used in the USA. I have also included a series of case studies on successful projects to provide a more comprehensive view of the project planning, implementation and evaluation process.

Acknowledgements

Firstly I would like to thank the Winston Churchill Memorial Trust for funding me to explore a cause that I am passionate about. Without their support this project would not have happened.

I am extremely grateful to the dedicated and hardworking fishery managers and biologists who are leading the push to improve recreational impoundment fisheries through the use of habitat enhancement. Their insightfulness, persistence and innovative thinking have inspired many others and provided me with the opportunity to learn from the world's best. Special thanks must go to my key hosts in each of the states visited. Brian McRae (North Carolina Wildlife Resources Commission), Shane Bush (Missouri Department of Conservation), Mark Porath (Nebraska Game and Parks Commission), Kurt Kuklinski (Oklahoma Department of Wildlife Conservation), Doug Adams (Bureau of Land Management), Dan Daugherty (Texas Parks and Wildlife Department), Brian McRae (Utah Division of Wildlife Resources) and Jeff Boxrucker (Reservoir Fisheries Habitat Partnership). All organised fantastic local itineraries and made the trip as enlightening as possible. They enabled me to meet a broad range of people and visit and explore many excellent examples of habitat enhancement. I would also like to thank Bill Frazier (NC BASS), Dennis Reynolds (Crappie Anglers), Stacey King (Missouri bass tournament professional and guide), Phil Lilley (Lilley's Landing Resort) and Kathy Weydig (Scuba Training & Technology) for organizing great field trips or events that made my trip memorable.

Thank you to my supervisor Michael Hutchison for supporting my application and providing invaluable feedback during preparation of this report

Finally I would like to thank my wife Emma, for all of her support throughout the Churchill Fellowship process and for permitting me to disappear for a few months to improve my knowledge in this field.

Executive summary

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Investigate strategies for increasing Australian impoundment fisheries productivity and improving recreational angling and regional economic growth

Highlights

- Viewing first-hand the benefits and improved fisheries as a result of installing fish attracting habitat structure into reservoirs and the large number of anglers who use these areas
- Meeting numerous recreational anglers who were passionate to improve local fisheries and were willing to volunteer so much of their time to make it happen
- Attending the Reservoir Fisheries Habitat Partnership conference and learning about all of the excellent projects that have been undertaken across the USA
- Understanding the huge scale for potential benefits to Australian impoundment fisheries and regional communities that can be achieved through fish habitat enhancement
- Establishing contacts and developing relationships with key fisheries researchers and managers in the USA that will enable dialogue and learning to continue

Key Recommendations

1. Habitat enhancement projects must set clear objectives and identify whether their primary goal is attracting fish for anglers or increasing reservoir productivity
2. The current status of the fishery and habitat availability must be assessed prior to developing and commencing habitat enhancement strategies
3. Volunteers should be used to minimise labour costs and increase community engagement
4. A diversity of habitat structure types and sizes should be deployed to create a range of habitats to benefit the most fish species and size classes
5. Habitat structures should have as much structural complexity as possible and not contain large open voids
6. Periods of low water levels should be opportunistically used to deploy fish habitat structures
7. Specialist habitat barges and heavy machinery should be used during large-scale projects to increase efficiency
8. Fish attraction sites should be established where they are accessible to shore-based anglers
9. The location and details of habitat enhancements should be made available to the public
10. Where water levels fluctuate significantly, lines of durable habitat structure and seeding grass beds or fast growing annuals during drawdown should be used to improve fish habitat
11. Economic assessments should be conducted before and after habitat enhancement activities to determine economic changes in the value of the fishery
12. There are many knowledge gaps that need addressing and a nationally co-ordinated approach should be developed
13. Pilots habitat enhancement projects should be undertaken in Australian reservoirs to identify the most effective strategies for Australian fish species and environmental conditions
14. Communicate the findings of this report to Australian fisheries managers, researchers and anglers

Program

Date	Place	People, Organisations and Activity
1-9 October	North Carolina, USA	Meetings, interviews and round table discussion with North Carolina Wildlife Resources Commission including presentations on the Churchill project and the management of impoundment fisheries in Australia. Site visits to rehabilitation projects at Rhodhiss, James, and Gaston Lakes, and Randleman and Jordan Reservoirs. NCWRC staff – Brian McRae (Piedmont Region Fishery Supervisor), Scott Loftis (Aquatic Habitat Coordinator), David Yow (Warmwater Research Coordinator), Jessica Baumann (Fisheries Biologist), Mark Fowlkes (Piedmont Aquatic Habitat Coordinator), Chris Wood (Fishery Biologist), Site visit to Oak Hollow Lake and interview - North Carolina BASS Federation and Fishing Guide (Bill Frazier, Conservation Director) Interview with Piedmont Triad Regional Water Authority - Randy Howard (Randleman Lake Warden) Interview with Crappie Anglers group (Dennis Reynolds and Charles Henderson) Site visit Lake Gaston and interview - North Carolina State University (Justin Nawrocki)
10-14 October	Missouri, USA	Meetings and interviews with Missouri Department of Conservation including presentations on the Churchill project and the management of impoundment fisheries in Australia. Site visits to Table Rock Lake and Lake Taneycomo, including diving on habitat enhancement structures and installing new structures. Tour Shepherd of the Hills Fish Hatchery Site visit to Table Rock Lake and interview with guide and professional tournament angler (Stacey King) MDC staff -Shane Bush (Fisheries Management Biologist), Ben Parnell (Fisheries Management Biologist), Dave Woods (Fisheries Management Biologist) and Justin Pride (Resource Assistant) Interview staff at Lilley's Landing Resort at Lake Taneycomo –

		Phil Lilley (resort manager and fishing guide)
15-17 October	Nebraska, USA	Meetings with Nebraska Game and Parks Commission including presentation on the Churchill project and the management of impoundment fisheries in Australia. Site visits to Conestoga, Holmes and Sherman Lakes NGP staff - Mark Porath (Aquatic Habitat Program Manager), Steve Satra (Program Specialist Fisheries Division) and Don Gablehouse (Fisheries Chief)
18-21 October	Oklahoma, USA	Meetings with Oklahoma Department of Wildlife Conservation and Reservoir Fisheries Habitat Partnership including presentations on the Churchill project and the management of impoundment fisheries in Australia. Site visits to Lexington Wildlife Management Area, Dahlgren Lake, Lake Konowa, Lake Holdenville and Prague Lake. ODWC staff – Kurt Kuklinski (Fisheries Research Biologist), Danny Bowen (Fisheries Biologist), Shelby Parker (Technician) RFHP – Jeff Boxrucker (Chair)
22-26 Oct	Arizona, USA	Meeting with the Lake Havasu Technical Committee including a presentation on the Churchill project and the management of impoundment fisheries in Australia Meeting with Bureau of Land Management and site visit to Lake Havasu. Dived on habitat in Lake Havasu and discussed appeal to divers with Kathy Weydig from the local dive shop, Scuba Training & Technology. Site visit to Lake Havasu to install habitat with BLM, members of Anglers United and volunteers. BLM – Doug Adams (Fisheries Biologist), Elroy Masters (Fish and Wildlife Program Leader) Anglers United – David Bohl (Chapter President), Gary Visconti (Vice President) Arizona Game and Fish – Russel Engel (Fisheries Program Supervisor), Lisa Osborn (Fisheries Biologist) California Department of Fish and Wildlife -David Vigil (Fisheries Biologist)

		Lake Havasu Marine Association – Bill Mackie (Coordinator)
27 October – 2 November	Texas, USA	Meetings and interviews with Texas Parks and Wildlife Department including presentations on the Churchill project and the management of impoundment fisheries in Australia. Site visits to Lake Conroe, Lake Athens and Lake Wichita. TPWD staff – Mark Webb (District Supervisor), Alice Best (Assistant Biologist), Bill Johnson (Technician), Richard Ott (Natural Resources Specialist), Kevin Storey (District Management Supervisor), Tom Lang (Fisheries Management Supervisor), Dan Daugherty (Fisheries Research Biologist) Texas State Senator Craig Estes Texas State Representative James Frank Lake Wichita key stakeholder Harry Patterson Jr., Lake Wichita Revitalization Committee -Steve Garner (Chair) Texas A & M University - Ryan O'Hanlan (PhD student)
3-8 November	Utah, USA	Meetings with Utah Division of Wildlife Resources including presentation on the Churchill project and the management of impoundment fisheries in Australia. Site visits to Willard Bay, Ogden River, Wanship Dam, Weber River and Rockport Lake. Attend the Reservoir Fisheries Habitat Partnership and present on the Churchill project and impoundment fisheries in Australia. UDWR staff – Craig Walker (Aquatics Section Co-ordinator)

Australian research priorities and knowledge gaps

Research and knowledge on structural enhancement to improve impoundment fisheries is in its infancy in Australia. Prior to my Churchill Fellowship to the USA, I conducted a survey of Australian fisheries researchers, managers and angling groups to collate information on what work has been undertaken in Australia, perceived knowledge gaps and research priorities. From the survey data and a search of the literature, less than six major projects focussing on improving recreational fisheries in impounded waterways through habitat enhancement could be identified. Only one of these projects was conducted at a scale where an impoundment-wide benefit may have been detectable, but that project targeted the protection and restoration of the threatened Macquarie perch (*Macquaria australasica*) and not recreational angling (Lintermans *et al.*2008). Several of the other projects involved small-scale introduction of timber constructions by anglers to aggregate fish in areas devoid of other structure. Little or no formal assessment was conducted of the effect on the fishery from these installations, however anecdotal reports from the anglers suggested their catch rates had improved.

The survey results indicated three main areas of knowledge gaps: the type of habitat and where to use it, how to evaluate the impact of habitat enhancement, and the return on investment from habitat enhancement. The key questions raised by survey participants are summarised below.

1. What is the best type of habitat to use and where should it be placed?

- What type of habitat should be installed?
- Is artificial or natural habitat better?
- How much structure needs to be installed?
- Where should the structure be located?
- How are habitat structures deployed?
- How to deal with fluctuating water levels?

2. How can the impact of habitat enhancement be effectively evaluated?

- How can the biological response to habitat enhancement best be monitored?
- What other parameters should be assessed?
- What sort of triple-bottom line evaluation can be used?

3. What is the return on investment for habitat enhancement

- What are the cost-benefit analyses of different strategies?
- What are the ongoing maintenance costs for different structures and strategies?
- How should investment be prioritised?

The top 5 research priorities identified were:

1. Does habitat enhancement just aggregate fish or does it boost productivity?
2. What is the cost : benefit of habitat enhancement?
3. What is the best way to deal with fluctuating water levels in impoundments?
4. How much habitat is needed?
5. How to effectively monitor the fish response to habitat enhancement?

This information was used to help frame the structure of the trip to the USA and the information sought during meetings and site visits to ensure that it was as relevant and broadly applicable as possible in Australia.

Goals and objectives of intervention activities

Management objectives must be clearly defined to increase the likelihood of success for a habitat enhancement project. The goal of most reservoir fisheries improvement projects is to improve angler satisfaction. This can be achieved by improving angler success or by enhancing other characteristics of the angling experience. The goal of a habitat enhancement project needs to be clear about whether increased fish numbers or aggregation of fish for anglers is the objective, as both can improve angler satisfaction, but require different approaches.


Anglers targeting fish around a buoy-marked fish attractor

There has been much debate regarding whether the installation of habitat enhancement structures actually increases fisheries productivity or just aggregates fish. This discussion has occurred in both the marine and freshwater sectors. In order to increase fisheries productivity there needs to be an improvement in recruitment (survival through to catchable size). This can occur through an increase in spawning success, juvenile survival through to maturity, or a combination of both (Miranda & Hubbard 1994, Bolding *et al.* 2004). Proponents for the installation of habitat enhancement structures frequently suggest the likelihood of spawning success improves following habitat addition due to the closer proximity and increased contact between mature fish. Opponents suggest the additional of structural habitat to aggregate fish results in increased harvest pressure and despite localized increases in fish density, potentially an overall detrimental impact to the fish population. The results from the reservoir fisheries habitat enhancement projects I investigated in the USA suggest that it is possible to actually improve a reservoir fishery's productivity, but it depends upon the type and scale of habitat enhancement implemented.

Installation of suitable habitats has been shown to be very effective at improving angling by aggregating fish. This strategy is most effective for primarily catch-and-release species (e.g. bass) where there is little harvest and additional angling pressure is unlikely to have a large impact on the fish population. The correct installation of structurally complex habitat in areas devoid of structure or where the structure is limited will attract sports fish and aggregate them for anglers to target. I was consistently informed during my Fellowship that in the absence of any other structural habitat, fish will utilise whatever they can, even if it as simple as a single rock or stake. All of the habitat structures described later in this report will attract fish if situated correctly. However, if the target species are panfish and experiencing harvest pressure, more caution needs to be exercised. The increased fishing pressure from aggregating a harvest species may result in population decline if the harvest becomes greater than recruitment. Different species utilise habitat enhancements at different stages of their life-cycle or times of the year. A structure installed for catch-and-release sports fish may also attract panfish at certain times of the year.

Improving reservoir productivity is far more complex, resource intensive and time-consuming than aggregating fish; however, the benefits can be substantially larger and persist longer term. Typically, a far greater number of variables need to be addressed to achieve a successful increase in fisheries productivity and the process may take many years. Environmental re-engineering and aquatic vegetation restoration are the most effective management activities to improve reservoir fisheries productivity. The goal of environmental re-engineering is to restore all necessary ecosystem services that support the fishery. This may include addressing nutrient levels, erosion, habitat depletion or absence, water quality, excessive predatory pressure, food resource levels, pest species and spawning requirements. Aquatic vegetation management conducted at a broad scale is a form of re-engineering. The process converts barren littoral shorelines or those with dense deleterious aquatic weeds into healthy, self-supporting aquatic ecosystems. The establishment of the vegetation boosts primary production, provides food for grazers, foragers and predators, improves water quality, stabilises shorelines and creates structural habitat. These factors are all necessary for healthy and productive reservoirs.

Attraction of fish and increasing reservoir productivity are not necessarily exclusive goals. If sufficient fish attracting structures are deployed in a reservoir, the increased spawning substrate, algal growth and associated grazing community on the structures may be enough to enhance sports fish and panfish populations by improving juvenile survival or increasing recruitment. The additional food resources created also have the potential to increase fish growth rates and the waterway's carrying capacity. Furthermore, habitat enhancements consisting of natural plant materials also introduce additional nutrients as they breakdown. A reduction of internal nutrient loading is common in reservoirs, as flooded terrestrial vegetation is lost through the natural decay and nutrient input rates decline (Ney 1996). The addition of a substantial amount of brush structures has been demonstrated to boost the growth of fish in nutrient limited systems (Jacobson & Koch 2008).

American bass fry and fingerlings utilising installed habitat structures for cover

The habitat enhancement strategy utilised will also depend upon whether the fish populations rely upon natural recruitment or are supplemented by stocking. Increasing the amount and quality of suitable spawning habitat may increase overall spawning output. If the fish population is reliant upon stocking then improving habitat for juveniles may increase juvenile survival and thus recruitment into the catchable proportion of the population. In Australia many of the key recreational angling species reproduce poorly in impoundments and many are essentially stocking-based put-and-take fisheries. The greatest benefits likely to be achieved will be realised from improved survival and growth of stocked fingerlings.

Types of habitat enhancement

A wide range of different habitat enhancements have been employed to improve habitat complexity in USA reservoirs and lakes. The objective of the habitat enhancement is generally to replicate the ecosystem functions of natural habitat utilised by fish in less disturbed environments. Habitat enhancement can be used to aggregate fish, provide more food, increase growth rates, improve reproductive success, improve juvenile survival and recruitment, provide protection from predators and improve water quality.

"Twenty years of work with artificial fish habitats, in warm water impoundments, have shown that a functional, artificial habitat structure can be designed for a specific habitat requirement for a particular fish species. The design can be successful in providing an opportunity for individuals of that species to accomplish the survival task for which the structure was designed..... In designing effective artificial habitats, the key is to determine what the fish's habitat needs are, to offer that type of artificial habitat in the correct location and on the appropriate native habitat type, within the particular impoundment. Then engineer and construct these artificial habitats to be structurally sound and provide long-lasting service, with a low digression rate." *Eric Wagner, Utah Division of Wildlife Resources (2013)*

Historically the materials used for habitat enhancement have largely been materials that are convenient, economic and readily available. As knowledge in the field grows, more specialist habitats are being created to service specific needs of some species. Generally a combination of habitat enhancement types is utilized to provide greater diversity of habitats for a wider range of species. The types of habitat used to manage and improve fish populations in reservoirs and impoundments can be divided into four broad groups: natural structures, constructed habitat including synthetic materials, aquatic vegetation and environmental re-engineering. The following is not an exhaustive review, but rather a brief summary of some of the fish habitat enhancements observed in the USA.

Natural structures

Historically, the most widely used habitat enhancements in USA reservoirs have consisted of natural structures such as trees and bushes. These structures potentially remain the most frequently used because they are relatively abundant, cheap to procure, easy to deploy and work can be undertaken by volunteers with minimal training. However, they should generally be considered as temporary structures which require replacement as the vegetation deteriorates over time.

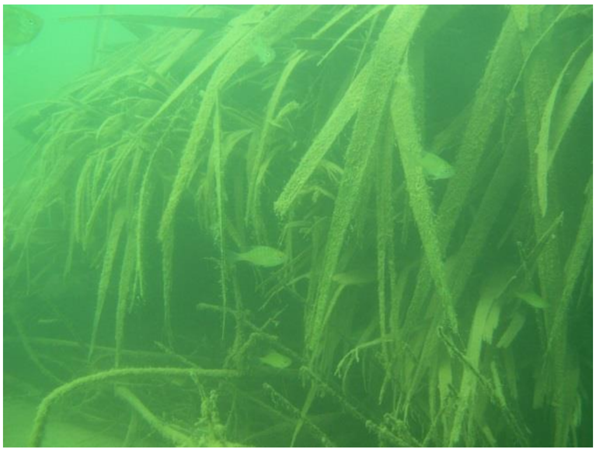
Brush Piles

Brush piles can be constructed from pruning discards, sawn off branches, old Christmas trees or any other large pieces of vegetation. They are easy to construct and deploy and therefore ideal for use by many community groups and volunteers. Brush piles are also the cheapest habitat structures to construct. The concept of brush piles is to replicate naturally fallen vegetation that has blown or washed into the reservoir. Brush piles deteriorate quite quickly so need ongoing replenishment, especially if periodically exposed to air during low water levels. Other factors influencing brush pile longevity include construction vegetation type, vegetation hardness, water temperature, exposure and aquatic biota. A low level of nutrients will be introduced into the waterbody as brush structures break down. This can often be beneficial in reservoirs where nutrient inputs are deficient. Medium to hard density timbers such as cedar, oak and mesquite are frequently used in the USA because they last 5-7 years before deteriorating too severely. Another advantage of harder timbers is they are less buoyant and therefore need less weight to anchor them in place.

Different styles of brush piles ready to be loaded and deployed (images A. Norris and MDC)

Brush piles 12-24 months post deployment (images BOR Lower Colorado Region Dive Team and A. Norris)

Palm fronds have generally been found to make poor brush bundles. The fronds lack the interstitial spaces and complexity observed in other plants and quickly break down leaving only the main stems. If used, palm fronds may only last 3 years before requiring replacement and have been found to benefit aquatic crustaceans (crawfish) more than fish.

Palm frond bundles in Lake Havasu, Arizona

One important point that was commonly impressed upon me was that freshly cut material should be used as soon as possible. In Lake Havasu it was observed that brush piles constructed from material cut more than a week previously required almost twice as much weight to sink due to the vegetation drying out. Additionally, stockpiling the brush attracted unwanted wildlife such as snakes and spiders which can pose a hazard to volunteers during construction.


Brush piles attract a wide variety of fish species and sizes (images BOR Colorado Region Dive Team and A. Norris)

Bamboo can be used as an alternate material to construct brush piles. Bamboo grows quickly and is considered a weed in many areas. Bamboo cuttings can be cemented in a bucket to form upright brush piles which provide great vertical structure. Alternatively the bamboo can be packed into more open structures to create smaller, more complex interstitial spaces. The stems and leaves can be quite durable when submerged, and the bamboo structures usually last 5-7 years before needing replenishment. Additional weight may be needed to sink bamboo compared to traditional brush pile materials because the centre of the stems is formed by hollow segments which create buoyancy.

Bamboo used to create vertical brush habitat structures

Brush piles are typically deployed by boat, with specialist habitat barges enabling the deployment of many bundles in a relatively short period of time. However, due to their comparatively light weight and small size, brush piles can also be deployed from recreational vessels and can be readily transported on trailers. A number of brush piles can be staged on the shore near the destination site or boat ramp, enabling the deployment vessels to spend more time dropping the structures into the water than transporting them. In areas where water levels fluctuate greatly, or during low water levels caused by drought or deliberate lowering of water levels, brush piles can be directly constructed on the shore below the normal low water line. This approach is extremely quick, easy and cheap, but can only be applied under the right conditions.

Brush piles attract a wide variety of species and size classes of fish. Smaller fish use the tight interstitial spaces to avoid predators and graze on the phyton which develops on the structure. These in turn attract the larger predatory species typically sought after by anglers.

A brush pile constructed on the shore during low water levels and a habitat barge deploying a load of brush piles (images MDC and A. Norris)

Brush lines

Where water levels fluctuate substantially or opportunistic low water levels occur, the installation of a brush line is sometimes considered. A wire rope is run out from the shoreline at an angle into deeper water and bundles of brush or trees are attached to the line to prevent them from drifting. The line is not run perpendicular to the shore, but at an angle to increase the amount of habitat at each depth. The brush line provides fish access to habitat during changing water levels and enables the fish to select their preferred depth at different times of the year. Brush lines work best with hardwood branches because the brush nearest the shore experiences wetting and drying cycles as the water levels fluctuate. Hardwood is more resistant to deterioration than softer timbers so will last longer. A marker buoy should be attached at the deep water end of the line to alert boaters and anglers to the structure's presence. A second sign on the shoreward end allows the angle of the brush line to be determined and fished effectively.

Brush lines in North Carolina reservoirs (images NCWRC)

Trees

Whole trees are another commonly used natural structure deployed to attract fish. Whole trees provide similar benefits and structural complexity to brush piles but at a larger scale. They replicate the natural introduction of large woody debris into reservoirs and can provide excellent habitat for many fish species. The preferred tree species are again medium to hard density woods. Medium density trees such as cedar frequently have more complex branching and provide slightly more complex structure, but hardwoods such as oak will last longer before deteriorating. Trees should be selected for a bushy crown and as much structural complexity as possible. The finer branches and leaves from whole trees will deteriorate at the same rate as brush piles, but the thicker branches and trunks will persist much longer. Whole trees sunk for fish habitat typically last between 7-15 years before breaking down, depending upon the site characteristics and tree type.

Ideal sized and shaped cedar trees to cut and install for fish habitat and a vertical pine tree created by weighting only the base of the trunk

There are a number of methods for deploying trees into reservoirs, but the most commonly used in the USA are sinking, cut-and-cable and felling. The process of deploying sunken trees is similar to that used for brush, but at a larger scale. The size and weight of whole trees make transport and loading much more difficult and can require mechanical assistance from an excavator or fork lift. Larger trees may not fit onto barges or are too heavy, so are towed by the vessel to the deployment site before sinking. The anchors to weight the structure are easier to attach prior to towing, but may necessitate quick deployment once the vessel has ceased headway. Alternatively, saddle weights can be thrown over sections of the tree once it is in location. Where agencies own a shoreline buffer zone or land parcel on a reservoir and are permitted to selectively fell, whole trees are frequently cut down as near as possible to the deployment site.

A felled tree and an angler hooked up on a fish from a similar felled tree

Where water levels are relatively stable and shoreline gradient is sufficiently steep, trees may be felled directly from the bank into the water, simulating naturally toppled shoreline trees. Greener trees are most suited to this practice as older trees tend to explode when felled. Skilled use of the chainsaw can direct the fell angle to be either perpendicular or acute to the shoreline. The tree may be left as it has fallen or can be attached to its stump to prevent it from drifting away. The latter method is called cut and cable and involves boring a hole through the fallen trunk and using a wire cable to attach it securely to the stump. This process may be required by waterbody regulators to prevent navigational hazards or protect water infrastructure.

A cut and cabled hardwood tree in North Carolina

Tree stumps

An alternative to using whole trees is to just deploy the stump sections to create a reef like habitat. Tree stumps are typically very heavy, and can have complex root systems creating plenty of niches for fish. The large dense timber will not deteriorate quickly so the stumps can be expected to persist for many years. The weight of the stump means no anchor weights are required to prevent them shifting, but also necessitates the use of a solid barge to deploy. The stumps are typically sourced free from land clearing, but require heavy machinery to transport, load and deploy them. Stumps have been deployed in a number of reservoirs and have been found to attract fish into areas devoid of any other structure. Ideally the stumps should be clustered to provide sufficient habitat for more than a single fish. When I went Scuba diving on a stump bed in Table Rock Lake I saw fewer small fish than other habitat types, but several large bass were observed cruising through the area.

A large habitat barge deploying stumps into Table Rock Lake, Missouri (image MDC)

Rock and rubble

One of the most basic, durable and naturally occurring materials is rock. Rocks may be placed singularly, in piles or in long reefs and provide a permanent habitat enhancement. In reservoirs large boulders can be scattered in flat, habitat devoid areas to provide a hard surface and ambush points. The use of large boulders is logistically difficult due to their weight and the necessity to use heavy machinery for transport and deployment. The best method for placement of any rock structures is during dam maintenance or annual drawdowns.

Creating humps of rock can be a more effective technique than scattered boulders. The interstitial spaces created provide forage-type habitats for a variety of aquatic insects, crustaceans and baitfish, and subsequently predatory species. Fish use depends on location, hump or reef size and stone size diversity. Utilizing a variety of stone sizes increases the variability in the interstitial gaps. Traditionally, rubble humps are placed on flats or shoals in flatland or hill-land impoundments. Suitable rubble includes sandstone or limestone, in sizes from fines to rip-rap. Broken concrete blocks are also regularly utilized as rubble material.

Rock mounds built in a Nebraskan reservoir and constructing a rocky reef in Table Rock Lake, Missouri (images NPG and MDC respectively)

Some rock structures are designed to not always be completely submersed. Rock walls and rip-rap are frequently constructed to prevent shoreline erosion. The portion of submerged rock can provide excellent habitat for aquatic organisms and fish. In some reservoirs in the USA sunken offshore breakwaters are created to reduce wave energy to prevent erosion or protect boating facilities. These wave dissipaters act as sizeable reefs and provide a variety of habitat benefits for fish. Predatory sports fish often are attracted to such areas by the accumulation of forage species and abundant ambush positions in the interstitial spaces. In areas where water levels fluctuate, rock fences are sometimes constructed. These lines of rock extend from the high water mark into deeper water and enable fish access to habitat as water levels fluctuate. Fish also have access to habitats at a variety of depths and may use the structures differently throughout the year. The drying and wetting cycles do not affect the rock as significantly as timber structures so the rock lines or fences do not deteriorate over time.

Rock and gravel fences installed to increase habitat complexity and enable access to finer gravel substrate for spawning nests (images MDC)

Another technique of creating habitat from rock involves creating rock lines. Where the substrate near the shore is comprised of consistent rubble and shale, rock lines can be scraped up during periods of low water level. The rock lines create habitat diversity in an area with otherwise homogenous structure and can also open up access to the finer substrate beneath the rubble layer. Such rock aggregations might be useful to improve fingerling survival of several species in Australia.

Gravel beds installed in a Nebraskan reservoir to improve bass and sunfish spawning (images NPG)

Rock can also provide spawning habitat. Gravel and cobble can improve the spawning habitat for a number of species and are commonly used in many USA states. In Lake James, North Carolina, gravel beds have been installed to improve spawning habitat for bass and sunfish. The sedimentation rate here is relatively low so the habitat is expected to be permanent and remain available. At this site a number of gravel beds 25 meters long, 6 meters wide and 4.5 meters high were installed in 7.5 meters of water. Anglers like to target gravel areas for nesting fish such as redear sunfish during the spawning season because of the aggressive manner in which they defend their nests. The natural recruitment of several nesting or gravel spawning species has improved since the introduction of gravel beds. In Australia, gravel beds may assist spawning of eel-tailed catfish (*Tandanus tandanus*).

Deploying gravel off a barge with a high power hose and redear sunfish nests in a gravel bed (images NCWRC)

Constructed habitat and artificial materials

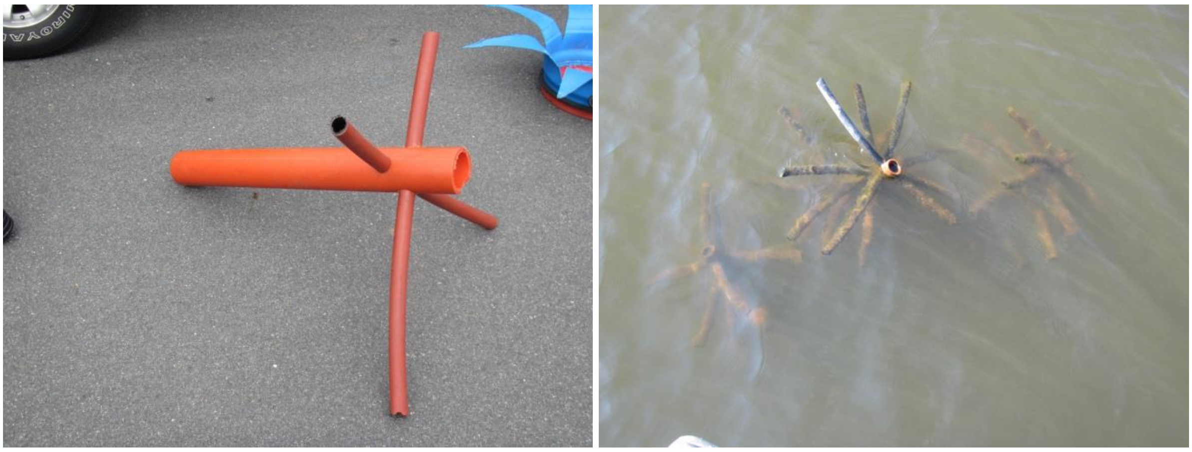
Constructed fish habitat structures can consist of various shapes and sizes, and made from a number of materials, but all serve the same purpose of providing underwater habitat for fish. Natural materials for habitat structures may not always be readily available or fulfil the intended purpose of habitat enhancement. A wide variety of convenient, recycled or cost-effective materials have been used to construct habitat structures for fish. The designs of these structures are only limited by the imagination of those building them, suitability to fish and the logistics of construction and deployment. The following is only a brief synopsis of some of the structures that I have observed at various sites in the USA. More comprehensive reviews can be found in Southern Division of the American Fisheries Society (2000), Tugend *et al.* (2002), Houser (2007) and Wagner (2013).

Plastic structures

Plastics are often used to create habitat structures because they are relatively light weight, easy to work with and durable. If made from UV stabilised materials, plastic structures will not deteriorate underwater like timber materials and once installed can be expected to remain intact and provide long-term habitat structure, barring damage or removal. They are often recommended for use in town water supplies because they have little impact on water quality. PVC pipe and irrigation tubing form the basis of many artificial habitat structures. These products are cheap, readily available and can be used to safely make simple, reproducible designs by people with limited handyman skills. This makes them excellent for construction by community groups and volunteers of all ages. Most pipe structures are not overly large or provide substantial vertical structure and are therefore most suitable for deployment in shallow water or areas where other structure is absent. A large number may need to be deployed to provide significant habitat to an area to attract fish. One of the advantages of pipe style structures is their relative resistance to snagging by anglers' hooks and lures. The round profile generally causes the hooks to slide over them. Larger diameter pipe is more hook resistant and also has the advantage that fish may utilise the inside of the pipes as well as the spaces between adjacent pipes.


Largemouth and smallmouth bass near PVC structures

Commonly used plastic and pipe designs include spiders, jacks, pineapples, starfish and Georgia cubes. The Georgia Cubes were initially developed by the Georgia Department of Natural Resources and consist of a square frame made from PVC pipe upon which plastic corrugated drain pipe is fastened. Before the top pipes are put onto the cube, gravel is poured into the open pipes, making the cube heavy enough to sink to the bottom of the lake and stay in place. These habitat structures are one of the currently favored constructions for use where larger habitat is required and natural materials will not be used. They are quick and easy to build in large numbers and have been found to attract a wide variety of species and size classes of fish.



A simple 'Jack' constructed from pipe and PVC tube and a more complex design after some time in the water. The benefit of the Jack is that it will always create vertical structure when deployed due to its design.

Spiders are the most commonly used form of pipe habitat. The designs can vary, but they are essentially constructed from small pipe pieces anchored into cement filled cinder blocks.

It is important to note that because plastic fish attractors are not solid structures (like rocks), they do not always appear very clearly on the depth sounder and can be difficult for anglers to locate. Lower quality sounders may have trouble distinguishing the location and size of these structures and often only appear lighter in colour than the lake bottom. To maximise the benefits to anglers it is recommended that the locations be marked by a buoy or the GPS coordinated be made available.


A Georgia cube and a 'Pineapple'. The 'Pineapple" was constructed from a cut down plastic barrel and the centre will be filled with gravel to provide weight and spawning habitat in areas with sediment accumulation.

Snow fence structures

Some of the largest artificial fish habitat structures have been created by wrapping snow fencing around a frame of PVC tubes. The resulting structures can be made a wide range of sizes, but remain relatively light and transportable. Smaller snow fence structures can be deployed by most boats, whereas larger structures require a barge to transport. The structures are sunk via gravel in the tubes or the attachment of concrete anchors. The snow fencing provides a large amount of vertical and horizontal surface area and readily develops a thick beneficial algal coating. A combination of other fish attractors is often used in conjunction with the snow fence constructions to make more complex structures.

A range of fish habitat structures created from snow fencing wrapped around a PVC frame. Note the thick algal growth in the lower two images (Images BLM and A. Norris)

A large amount of snow fence habitat was deployed in Lake Havasu, Arizona, but managers have shifted away from the design because in some cases the snow fencing has detached from parts of the frame and become a potential navigational hazard.

Snow fencing detaching from the PVC pipe frame

Commercially produced fish habitat structures

The popularity of habitat enhancement activities in ponds, lakes and reservoirs in the USA has resulted in a large number of commercially fabricated fish habitat structures becoming available. The majority of structures are constructed from synthetic materials and come in a wide range of shapes and sizes for different applications. Many are quite light and sold in kit form to make them easy to transport and deploy. Assembly typically involves slotting pieces together to form the desired structure. Advantages of these structures include greater snag resistance to fishing hooks and lures than brush, durability (do not break down like timber) and the lack of special equipment required to assemble and deploy them. Covering large areas with high densities of commercial fish attractors can be expensive, and therefore they are rarely used for large-scale projects. The following section describes some of the specific commercial fish attractors that I encountered in the USA.

Fishiding™ artificial fish habitat products are constructed from reclaimed PVC. Each unit consists of a rigid PVC base with various lengths, widths and sizes of substantially flat limbs protruding. The limbs can be hand moulded to create the desired shape of the end-product

A Fishiding™ product being bent into shape prior to deployment and being utilised by a bass

Honey Holes™ produced by Pond Kings Inc. are commercially produced polyethylene structures designed to provide habitat for fish in ponds and reservoirs. Three different designs are available to suit a range of applications and target species. The manufacturer suggests placing the structures in clusters in water deeper than 1.2 to 1.8 meters. The 'Honey Tree' is the tallest structure and can be placed on the substrate or suspended to provide habitat in deeper water. The shorter structures are designed to be deployed in shallower water (0.9-1.2 meters) to provide habitat for forage species.

The range of Honey Hole™ fish attractors produced by Pond Kings Inc. (image Pond King Inc.)

Fish 'N Trees® consist of flat plastic 'leaves' attached to an anchored central 'trunk' to form an underwater artificial 'tree'. The structures are reasonably durable and because the leaves are buoyant and rotate freely, fishing hooks tends not to snag on the structure. The main issue with this design is the leaves may sag from accumulation of epibiota or silt, reducing their effectiveness as fish habitat. A maintenance program, or design modifications to increase leaf buoyancy, may alleviate this problem.

Accumulation on the Fish'N Tree's leaves can cause them to sag resulting in decreased effectiveness (image BOR Lower Colorado Dive Team)

Mossback™ fish habitat provides a range of artificial products to increase habitat complexity and attract fish. The design is based on a central pipe with many slits through which angular strips are inserted to provide lateral structure. Individual or multiple pipes can then be installed on a base to from an array of habitat designs.

Examples of the commercially produced Mossback™ habitat structures, including sizeable Mossback city (images Mossback and NGP)

In some reservoirs, Mossback racks are being used in a similar manner to brush lines. A long line of Mossback structures lying horizontally are attached to a wire running diagonally from a point at the high water level towards deeper water. The habitat is installed during a period of low water and provides structure for fish across varying water levels and depths.

A Mossback rack running at an angle to the shoreline and a home-made equivalent. A chain of these can provide fish habitat throughout fluctuating water levels

Constructed timber habitat

Although plastic is the very commonly used to create fish habitat structures, some artificial habitat is constructed from other materials. The use of timber is also very popular for making habitat, with the most common designs incorporating pallets, fish cribs and stakes.

Pallets

Pallets are frequently used to construct fish habitat because they are cheap, abundant, already contain some structural complexity and are easy to arrange in a variety of configurations. Pallets may be arranged in a triangle or square and used as individual units or stacked to form pallet towers. Individual pallets can also be placed vertically in the water column or stacked on top of each other horizontally. Pallets can be weighted down with rocks, concrete slabs or cinder blocks and the internal voids can be filled with additional materials such as brush to increase the size diversity of interstitial spaces. Hardwood pallets are preferred because they are more resistant to decay and require less weight to anchor in place. Painted or treated pallets should be avoided to prevent leaching of contaminants into the water. Although pallet structures can be deployed from a boat, deployment is much easier during periods of low water when construction can occur on site.

Bass fingerlings near a pallet and brush structure and a similar structure which has collapsed

A variety of fish habitat structures created from pallets. The last image shows a construction using plastic pallets to provide overhanging shelter (images NGP)

Fish cribs

Fish cribs are long lasting, complex, deep-water structures designed as a refuge-type habitat. They provide protection for juvenile fish and improve recruitment of panfish and game fish. The amount of material in the cribs can vary depending on the desired range of interstitial spaces. The cribs used by the United States Fisheries Service were rectangular, 2–4 m per side in length and 1–2 m tall, and were constructed of green hardwood logs 8–15 cm diameter, stacked "log cabin" style (Bassett 1994). Logs can be bound together with galvanized wire, polypropylene rope, nails, or rods pushed through holes drilled through the logs.

The Porcupine Crib was initially developed by Pennsylvania Fish and Boat Commission to replace short-term more degradable habitat structures such as brush. Their construction typically consists of rough-cut green timber. Structures can be made in various sizes, but are typically 1.0-2.0 meters high and designed to be submerged in 3-5 meters of water. Several cinder blocks are attached to the structures to anchor them in place. Fish cribs are relatively inexpensive and easy to construct, although deployment is far easier off a barge than a standard boat. Pennsylvania Fish and Boat Commission (Houser 2007) recommend 10 to 20 porcupine cribs are placed in a row or alternating row pattern, with 1.2 to 2.4 meter spaces between individual structures. A typical placement density is approximately 50 structures per hectare.


A Pennsylvanian fish crib and a more open design constructed from logs (images PFBC and NGP)

Stake beds

Many artificial habitat structures are designed on a horizontal cover principle. In contrast, stake beds and post clusters are designed to create vertical long-lasting, functional, shallow-water cover. Stake beds are often constructed using wooden stakes or plastic pipes set into a suitable frame and anchored down by weights. Post clusters utilize common agricultural fence posts or logs, driven into the impoundment's substrate in a cluster pattern, to create shallow-water, vertical ambush cover for predators. Simple vertical habitat provides camouflage-related benefits to sports and panfish. The hard structure protection from predators and promotes growth of epibiota providing a food source for small fish.


Pre-fabricated stake beds to provide vertical structure for fish (images PFBC)

Aquatic re-vegetation

Aquatic vegetation can play a major role in fish production as a habitat, but this is dependent on the species and abundance of both the fish and the vegetation. Some species of submerged aquatic vegetation provide excellent juvenile or young-of-the-year survival habitat, while other vegetation species may enhance foraging opportunities for adult fish or spawning habitats. Past research in the USA suggests that aquatic vegetation coverage of an intermediate proportion of the lake's total area provides the greatest benefits to warmwater sport fish communities (Crowder & Cooper 1979, Wiley *et al.* 1984, Bettoli *et al.* 1992, Miranda & Pugh 1997). The feeding efficiency and growth of sports fish was highest at intermediate levels of aquatic plants coverage and reduced when vegetation densities provided too much structural complexity and cover (Crowder & Cooper 1979, Bettoli *et al.* 1992). The total production of panfish may not be as limited by high coverage of aquatic vegetation and may benefit from even higher abundance of aquatic plants (Crowder & Cooper 1979). However, high coverage by aquatic plants can make angling very difficult and angler catch rates may decline despite the presence of more fish.

In recent times, fisheries biologists in many States of the USA have placed increasing focus on the restoration of native aquatic vegetation in reservoirs (e.g. restoring aquatic vegetation has become a key component of fisheries habitat enhancement in North Carolina, Texas, Nebraska and Oklahoma). Healthy communities of native aquatic plants generally support higher fish densities, reduce the risk of predation and provide habitat for species that are reliant on structure. Vegetation provides habitat for fry and juvenile sports fish as well as forage species. Improving juvenile survival can lead to significant increases in the population size of key angling species. The aquatic vegetation in reservoirs is often lacking due to high fluctuations in water levels, insufficient suitable substrate and a lack of propagules for colonization. Restoration of aquatic vegetation can lead to the attraction of fish and increased reservoir productivity.

The issue of aquatic vegetation management is more complex in the USA than in Australia. Many USA reservoirs have suffered extensive invasive weed issues, particularly from hydrilla (*Hydrilla verticallata*), eurasion milfoil (*Myriophyllum spicatum*), salvinnia (*Salvinnia* spp.) and water hyacinth (*Eichhornia crassipes*). These plants form such closely matted vegetation beds that larger fish avoid areas where they are prevalent. Additionally these weeds become navigational issues and frequently choke boat channels and docks. Mechanical and chemical management strategies are in place to restrict weed abundance, but grass carp have also been introduced in many places in the USA to provide additional grazing pressure. The issue with grass carp is they readily feed on native aquatic plants as well as the invasive species. Once the invasive plants are under control, the grass carp frequently then decimate the native aquatic vegetation and prevent it from re-establishing. Many USA reservoir managers have the complex and difficult task of finding a satisfactory balance between the abundance of invasive vegetation, native aquatic vegetation and grass carp. Exotic aquatic plants, including salvinnia, water hyacinth and cabomba, are also a problem in some Australian reservoirs, but the use of grass carp to manage them is not permitted. There would be less need for the screened enclosures to help native vegetation establish following planting.

Preliminary trials have been undertaken in many USA reservoirs to identify which native species of aquatic plant are most suitable for re-establishment. Trials were conducted in small plots, screened with metal fencing to keep grass carp and turtles from grazing on the plants. Species that did best under these trials were then generally planted more broadly in larger screened areas. Anglers frequently target sports fish around these enclosures. The majority of plant propagation and planting was carried out by school groups and volunteers under the technical supervision of fisheries staff. Special propagation beds were built on shore to grow enough plants to cover large areas. The native emergent plant, water willow (*Justicia americana*), grows well and is also relatively undesirable to grass carp and other grazers. This species has been the most widely used to re-establish extensive vegetation in reservoirs. Once this species has established, other aquatic plants tend to follow.

A trial vegetation enclosure used to determine aquatic plant species which will readily return to a reservoir and a larger multi-species enclosure which has been dominated by one or two successful plant species

In reservoirs where the aquatic vegetation has been successfully re-established, strong improvements in recreational fisheries have been observed. At Lake Athens a complete revival of an overstressed fishery occurred following the return of the littoral vegetation. The recruitment, abundance and growth rates of bass and crappie species all increased, resulting in a now thriving fishery. However, rehabilitating reservoir vegetation is a time consuming process and a long-term approach. It frequently takes 3-4 years before the plants really establish and start spreading outside of the screened areas but takes 7-9 years before system-wide effects are readily apparent. Prolonged low water levels or drought can have a huge impact on re-establishment success. Aquatic vegetation rehabilitation is most successful where water levels are relatively constant. The technique can be utilised in reservoirs which experience large seasonal fluctuations, although the species of plant selected need to be more tolerant to long periods without inundation and limited rainfall. However, the risk of failure in this situation is much greater and the planting of annuals on exposed shores may be more effective.

Before (2006) and after (2013) images of a shoreline successfully revegetated. Note the angler fishing the vegetation margin in the background (images TPWD)

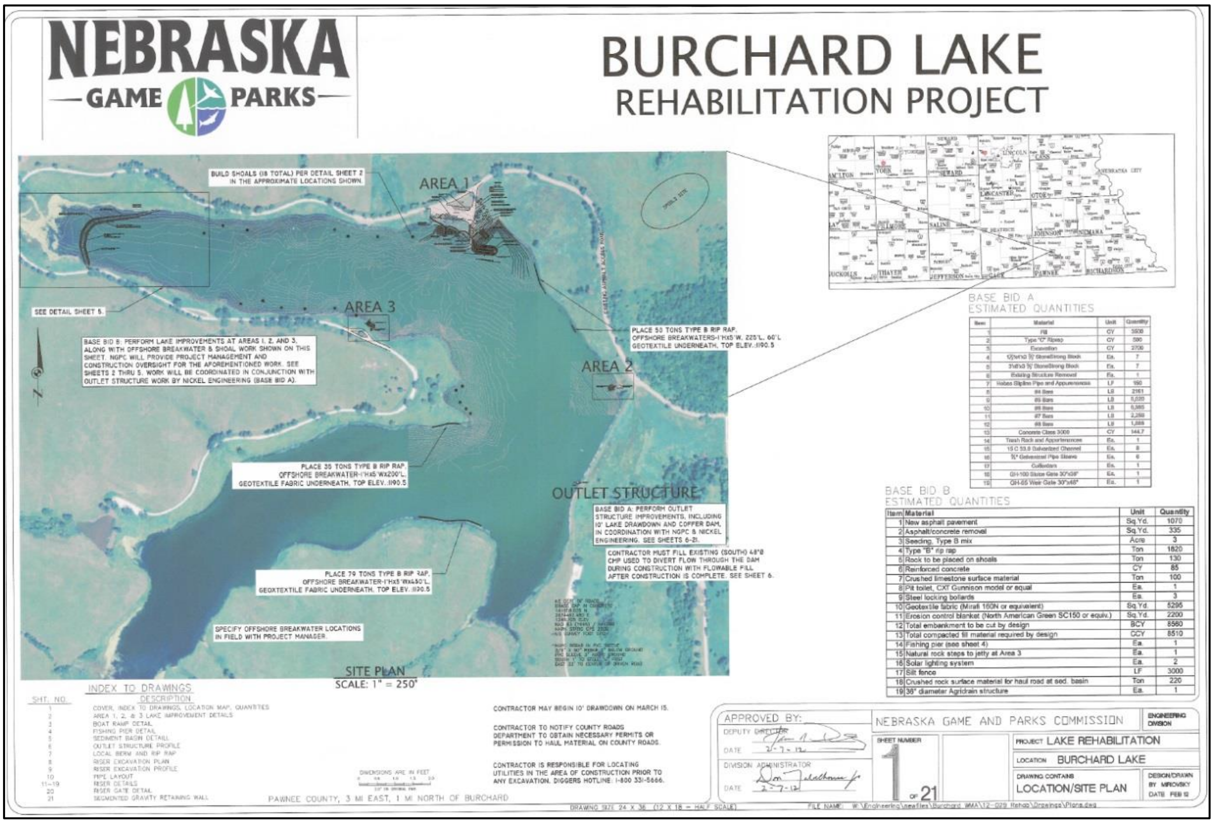
Environmental engineering

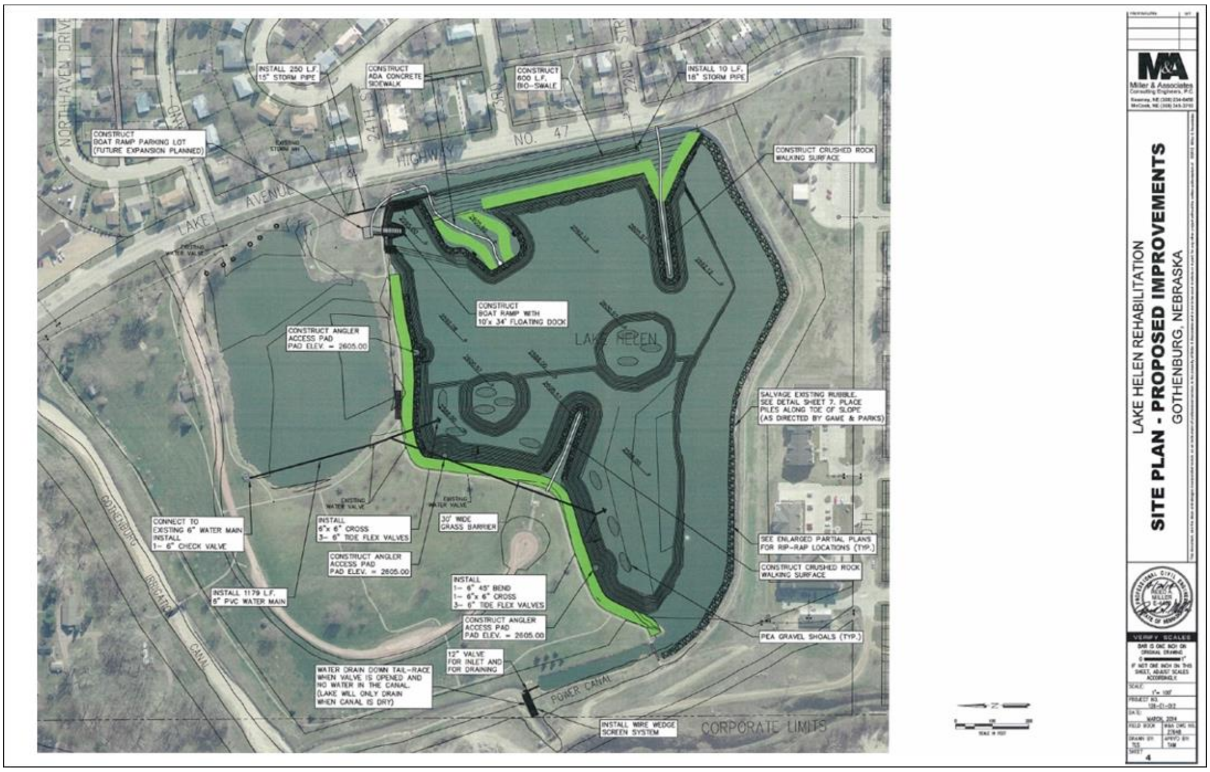
The most comprehensive and long-term approach to using habitat enhancement for improving reservoir fisheries is environmental engineering. In Oklahoma, Nebraska, Florida and Pennsylvania environmental re-engineering has been used to completely rebuild and restore reservoirs specifically to maximize fisheries potential. This is a holistic approach to reservoir management that uses a combination of fish attracting structures, vegetation restoration, improvement in spawning habitat and re-sculpting the topography of the waterbody. The strategy is most effective and generally only applied where it is possible to control impoundment water levels. Environmental engineering of reservoirs is typically conducted at a large scale and thus can be expensive to implement; however there are many benefits to using this approach.

The budget estimate (USD) for environmentally re-engineering Conestoga Reservoir, a small 93 ha reservoir in Nebraska. The goal of the rehabilitation project was to improve aquatic habitat, water quality, angler access and extend the life of the state recreation area (data from The Flatwater Group Incorporated 2012).

Preliminary estimate of probable construction cost – 95% **Area**	**Cost (USD)**
Boat ramp area	$1,213,575.93
North Shoreline	$438,451.99
Northwest arm	$1,082,538.49
West offshore breakwater and excavation	$292,423.96
Southwest arm and channel excavation	$521,554.72
Main (SW) sediment dike	$1,104,351.35
Southwest sediment basin	$955,994.20
Southwest water quality cells	$353,787.41
South shoreline	$280,075.01
South angler access path and parking area	$93,597.87
Estimated construction cost subtotal	***$6,336,350.87***
Estimated total cost of construction	***$6,336,350.87***
Contingency 15%	***$950,452.64***
Estimated probable cost of construction	***$7,286,803.57***
Alternative 1 (NE sediment dam and dike)	$72,594.64
Contingency 15%	$10,889.2
Estimated probable cost of construction – Alternative 1	$83,483.83
Estimated construction cost subtotal with Alternative 1	***$7,370,287.40***
Total net volume for sediment excavation	***485,147 m^3***
Total net volume for excavation with Alternative 1	***487,556 m^3***

The initial step is assessing the reasons for the poor performance of the fishery. Detailed plans are then developed outlining the appropriate rehabilitation activities to be undertaken. Examples of plans for an urban reservoir and one located in a wildlife area are shown below.





Examples of plans outlining the environmental re-engineering activities to be undertaken at a reservoir in a wildlife area (top) and an urban reservoir in Nebraska (bottom). These plans were developed during the Burchard Lake Rehabilitation Project and the Lake Helen Rehabilitation Project, respectively (NGP 2012, Miller and Associates 2012).

Excavating sediment and re-contouring the substrate topography in a small drained reservoir (image NGP)

The start of environmental engineering typically involves draining the reservoir completely, or at least drawing the water level down significantly. The exposed substrate is then allowed to dry and harden sufficiently for heavy earth moving equipment to be used to create bottom contours that are beneficial to the species to be stocked and anglers.

At the tail end of the reservoir where the feeder streams enter, sediment traps are often constructed has to improve water quality. These ponded areas slow down the water velocity so that sediment drops out of suspension, resulting in clearer water in the main reservoir body. Another advantage of the settlement ponds is they provide a great area for aquatic vegetation to establish and can form small wetlands. These provide a range of ecosystem services to fish and other aquatic and avian fauna, as well as acting as a biological filter by utilising excessive nutrients from the incoming water. Decreases in nutrient levels entering the main body of the reservoir can greatly reduce the frequency and severity of harmful algal blooms in some reservoirs.

Constructed wetlands designed to trap sediment, improve water quality and create habitat and nursery areas for fish (images NGP)

Shoreline erosion is a major issue in many larger reservoirs due to the fetch length of the predominant winds generating significant waves and wind chop. Historically, extensive rip-rap has been placed around the shoreline to prevent this; however in recent years the preferred method in Nebraska has been to build offshore breakwaters parallel to the shore. These structures dissipate the wave energy, reduce lateral sediment drift and create a calm, shallower area where vegetation can grow to provide habitat to juvenile fish and prey species. It is expected that the native vegetation (especially water willow *Justicia americana*) will spread along the shoreline to provide further protection from erosion. The offshore barriers also directly provide useful habitat for many fish species.

Off-shore breakwaters protect the shoreline from erosion and create additional fish habitat and protected areas for aquatic vegetation to establish (images NGP and A. Norris)

Improvements to angler access form a key component of all comprehensive reservoir fishery enhancement programs. Projects are undertaken to improve the recreational fishing experience thus making it is essential to make it easier for anglers to access the upgraded resource. This can be undertaken through the installation of rock groins, boat ramps, fishing pontoons and access trails around reservoirs. Many of the reservoirs that undergo environmental re-engineering are utilized by multiple user groups who need to be taken into consideration during the planning, design and construction phases. For example, Sherman Lake in Nebraska is used for hunting of water fowl and terrestrial game, fishing and boating. Sections have been designated as wilderness and wildlife habitat, fish habitat and specifically for recreational boating. This ensures that the maximum economic, social and environmental benefits are gained from the large investment and temporary inconvenience to waterway users. Demonstrating a high level of benefit to the community is often essential to gain support for larger projects and addressing the needs of a wide variety of stakeholders increases this value.

A series of rock groins have been installed to reduced wind erosion, provide additional habitat for fish and improve angler access (images NGP)

Nebraska has been using environmental engineering for at least 18 years to manage fisheries and is one of the key proponents of this type of fishery restoration. The State historically had very few natural lakes, so numerous reservoirs were constructed. As these water bodies aged and their fisheries declined, long term solutions were sought. Many reservoirs occur in urban areas and experience high usage and fishing pressure. The installation of fish attracting habitat alone was not believed to be sufficient to overcome the urban and angling pressures on fish populations.

Nebraska now focusses on completely re-engineering lakes and reservoirs for long-term improvements in their fisheries. Lakes are typically drained where possible, heavy machinery is then used to re-sculpture the bottom to create depth heterogeneity, install groins and breakwaters for erosion control and angler access and add rock mounds and gravel beds to assist spawning in certain species. Nebraska places priority on improving angler access, with fish attracting structures added to aid anglers, particularly near shore-based angler access points. In deeper holes excavated around rock groins, a high density of brush and PVC structures are typically added within casting distance to attract fish to the areas where anglers can target them from the shore. Rehabilitation occurs in most lakes right across the State and in a recent survey anglers listed habitat enhancement as the number one issue for their fisheries. A survey by Nebraska Game and Parks shows that habitat enhancements have resulted in a significant increase in the number of anglers using the rehabilitated reservoirs (angler days/year) especially compared to untreated dams. The demonstrated success of Nebraska Game and Parks Commission projects has meant that they are frequently requested to provide technical advice on the restoration of old reservoirs and the design and construction of new dams to prevent the occurrence of habitat issues.

The large-scale projects undertaken in Nebraska have spawned a growth in contractors and consultancy companies associated with environmental engineering projects. This has led to:

- Economic growth
- The emergence of a small industry
- Expansion of work into other states

'Rock stars' and other fish attracting structures are added to reservoirs in Nebraska prior to re-flooding to provide areas for improved angling (images NGP).

Installing habitat enhancements

A range of factors need to be considered when selecting where to install fish habitat enhancements in a reservoir to achieve the best success. These include the biological and behavioural characteristics of the target fish species, habitat type, presence of existing structure, angler access, availability of materials, material transport, available deployment equipment, substrate type, water level fluctuation, sedimentation, thermocline depths, boat traffic and other recreational waterway use and water conditions.

There are several strategies regarding the deployment of habitat structures with respect to existing structure. Many of the USA fisheries biologists I met typically placed additional habitat structure in areas where fish naturally aggregate. The intention was to increase the fish attraction potential of the existing structure and retain fish in the area for longer. Some of the favourite locations for habitat enhancement included the end of underwater points, near sharp changes in the bottom topography (drop-offs), flooded road crossings, the margins of aquatic vegetation and old river channels. Alternately, habitat enhancement was undertaken in sections of a reservoir where habitat was very poor or devoid. Installing structures in these areas provides a focal point for fish and can be very effective at attracting and retaining fish in the area. When there is little structural complexity fish will frequently remain mobile. The addition of habitat provides the fish with a place to rest, wait in ambush or feed, leading to them lingering longer in a small area. This benefits anglers by providing them a greater probability of encountering a fish in that area.

Habitat enhancement structures have been installed around points extending underwater to attract more fish and retain them in the area longer.

Water depth is a critical factor in determining the placement of artificial structure. One of the most important considerations is the thermocline depth. The water beneath the thermocline is often depleted of oxygen and rarely used by fish. If structures are to be accessible to fish throughout the year they need to be installed above the thermocline. Although thermocline depth varies between waterbodies, the average in USA lakes was generally between 4.5 metres and 6.0 metres. The most common depth for placing habitat structures was therefore 3.5-4.5 metres deep. This depth allows for some water level fluctuation, ensures the structure is deep enough to avoid being a navigational hazard and provides sufficient water above the structure for fish to school. The managers of some reservoirs also require structures to be placed in water where the top of the structure had more than 1.5-2.0 metres of water above it at conservation pool level for boating and water-user safety.

Many fish species utilise habitats in different depths at different times of the year, driven by both biological and abiotic factors. The installation depth of a habitat structures should take into consideration the preferences of the target species. Some species, such as crappie, aggregate in deep water during winter when the thermocline is no longer present. The placement of brush piles in depths around 10 metres was commonly reported to be effective at attracting crappie species and providing excellent angling opportunities during winter. Conversely, most of the bass species in the USA frequent shallow water (<2 metres) during the warmer months. Habitat structures such as spiders and brush piles are often placed in these shallow areas to attract fish and hold them there longer. Habitat that is set too shallow can be surrounded or smothered by dense macrophytes and may be of limited value. Locations need to be deep enough to avoid marginal weed, but still close enough to shore for bass to use and anglers to target.

The location, sedimentation rate and type of substrate all need to be taken into consideration when deploying habitat structures. If the substrate is too soft then the introduced habitat may sink deeply into the sediment, reducing its effectiveness. This is particularly important for heavier structures such as rocks, stumps and heavy timber constructions. Sometimes the sediment load entering a reservoir can prevent the installation of habitat structures in the upper end of the lake. Large amounts of silt may be deposited in these areas creating a soft substrate into which structures will sink. Additionally the sediment load may deposit too much silt upon the structures and either bury them or inhibit the growth of epibiota. Habitat should instead be placed lower down the reservoir where sedimentation is less of an issue.

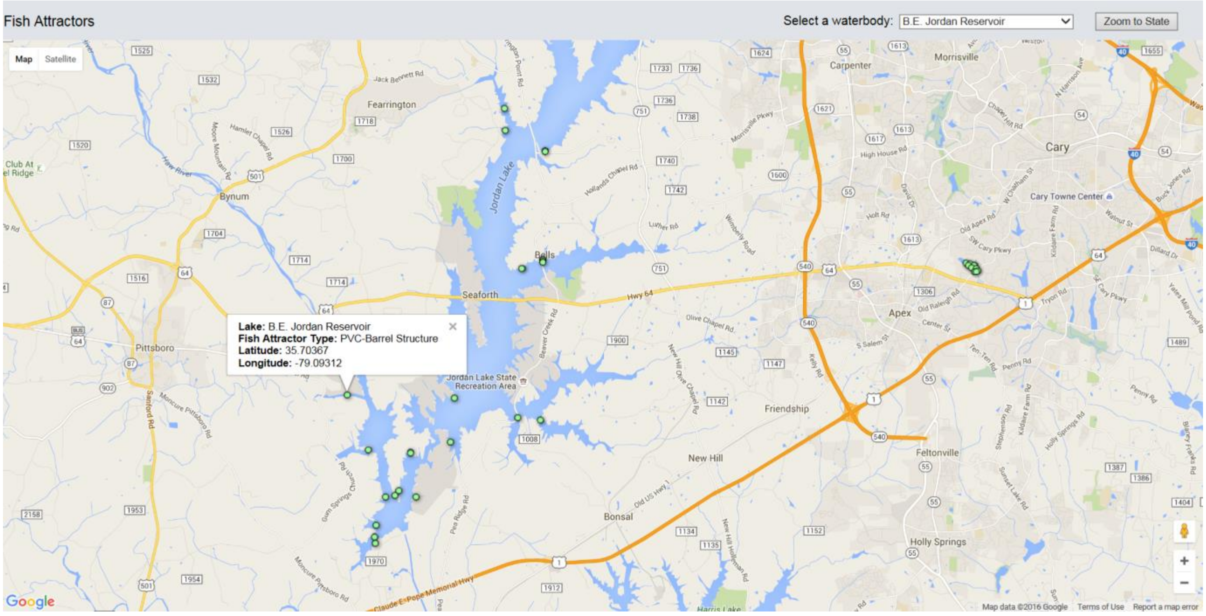
Accessibility by anglers and the distance of habitat structures from boat ramps should also be considered. Anglers are more likely to fish at habitat structures that are closer to a boat ramp than those that are located at distal points of the reservoir. Similarly, some fish attracting habitat should be located in areas which can be accessed by shore-based anglers and be within or just beyond casting distance. Where shore access points such as breakwalls, groins or floating piers have been constructed, habitat structures should be densely deployed to attract fish into the area. Placing structures beneath floating piers is also an excellent way to attract fish and hopefully increase angler catch rates. This is particularly useful for assisting anglers with limited mobility to improve their catch.

The location of all habitat structures should be recorded along with parameters such as the type, size, deployment date and water depth. If the habitat has been installed to attract fish for anglers then the location and details should be made available to the public. This does not occur in all states of the USA for a variety of reasons. For species that are typically released after capture, identifying the location of the habitat enhancements is unlikely to have much detrimental impact on the population. However, for panfish such as crappie, bluegill and redear sunfish, clearly marking the spots where they aggregate can increase the harvest pressure, sometimes beyond what the population can sustain.

In some reservoirs, the location of installed habitat structures is marked with buoys. These make it easy for anglers to visually identify where habitat has been placed so they can target that area. The use of buoys varies between states and even individual waterbodies. In some areas there are management concerns over the buoy costs and the potential for litigation if struck by a boat. In Missouri, signs are sometimes attached to trees on the shoreline to indicate the nearby presence of installed fish habitat. The buoys and signs not only indicate sites for anglers to fish, but they also are a useful way to inform people about the work that has been undertaken and provide acknowledgement to sponsors who have made it possible. This is important to ensure program continuity and to maximize benefits to the angling communities. A disadvantage to marking habitat structure locations is that too many anglers may concentrate their efforts in fewer places, increasing the possibility of overharvest. An option to prevent this problem would be to mark some structures, but not all, or to put in so many structures that over-targeting is unlikely.

Examples of signage marking the location of habitat enhancements.

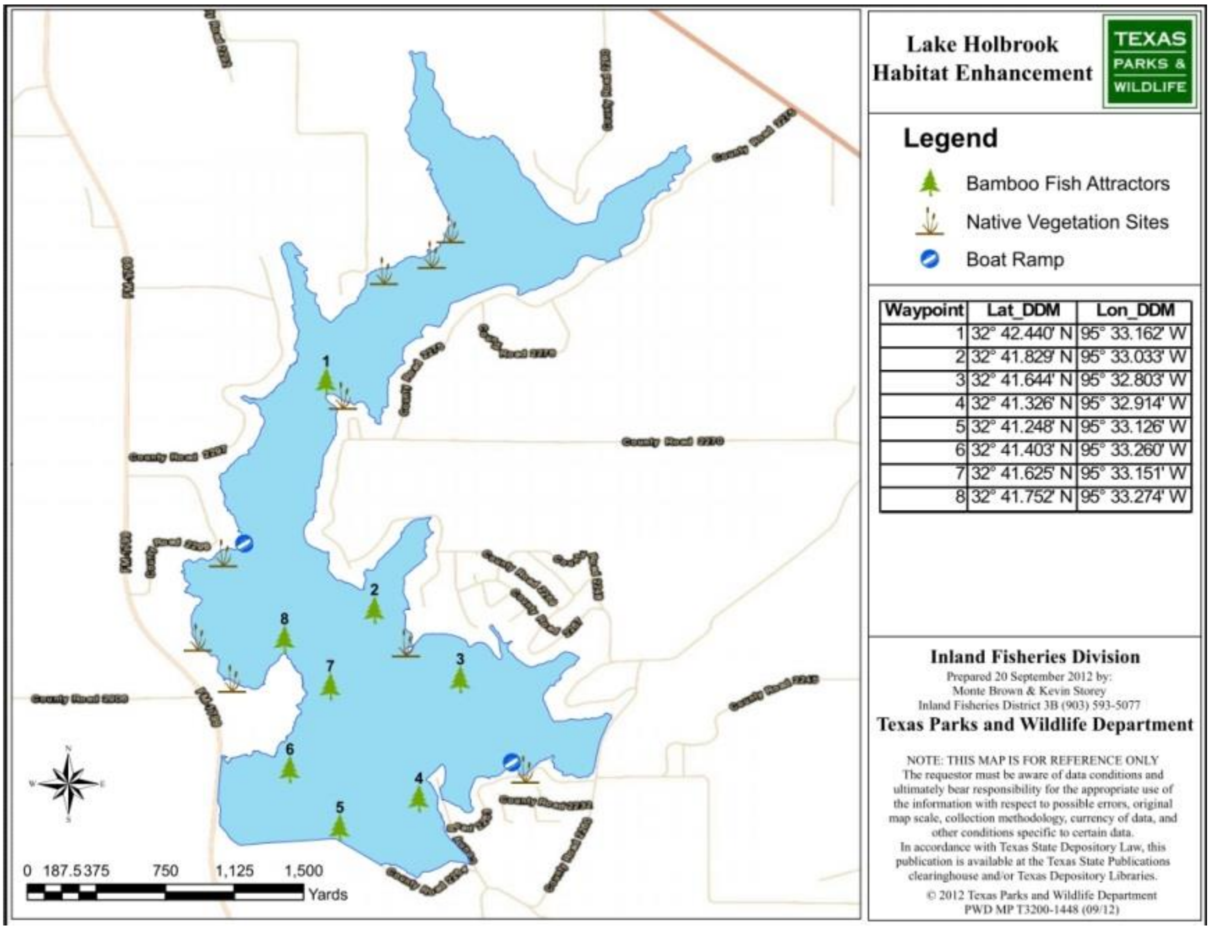
Instead of marking the site of habitat structure, many agencies make the data available to anglers via a website, phone app, interactive online maps or paper charts. Missouri and North Carolina have both developed excellent interactive maps with the location of fish attractors in most reservoirs of their state. Texas has created a website where anglers can download the GPS coordinates and structure details from their habitat enhancement projects as well as PDF maps of each reservoir. At Lake Havasu, Arizona, the locations of habitat enhancements are not freely available, but a map can be purchased identifying key areas where habitat has been installed. There is some interest to improve this situation and make the data more readily available.



A screen shot from North Carolina Wildlife Resources Commission's online interactive Fish Attractor Map showing Lake Jordan. http://ncpaws.org/wrcmaps/WRCFishAttractors.htm

The use of buoys, signs, webpages and maps are highly valuable tools to increase the success rate of visiting anglers who may not know a reservoir very well. This is particularly true for learner anglers or tourists who hire smaller boats which may not necessarily have a quality sounder. These anglers can use the map to drive to an area where habitat installations should attract fish and wet a line with the knowledge they are fishing in a likely spot.

Habitat enhancement structures have been deployed in a variety of patterns, including solitary structures, clusters, lines, circles, squares, scatters and mounds. The most common approach used is to deploy lighter and smaller structures in clusters. Several brush piles or small trees are dropped in the same location and allowed to settle on the bottom however they land. The most effective deployment pattern is likely to vary between habitat structure types, but unfortunately knowledge on the topic remains limited. Several fisheries groups are about to commence research projects to address this knowledge gap. It is anticipated that information on the most effective deployment strategies will enable the amount of structure required for effective results to be optimised, thus potentially lowering the cost of enhancement projects or enabling more areas to be addressed for the same resources.



An online reservoir habitat enhancement map for Lake Holbrook, created by Texas Parks and Wildlife.

There is also limited information on recommendations for specific quantities of artificial structure to place into reservoirs for fisheries enhancement. More research is needed. Given the cost of habitat improvements, knowing the optimal amount of artificial habitat to add is an important management decision. The management objective of a project is vital in determining how much habitat should be installed. Attracting fish to known locations to assist anglers can be achieved using far less structural enhancement than increasing reservoir productivity. Attraction can be achieved using a few or many structures placed in the right locations, whereas improving productivity requires a reservoir-wide effort and potentially addressing multiple issues.

Whilst quantitative data on the quantity of habitat needed to achieve specific management objectives is rare, some data exists for fishery responses to various levels of aquatic vegetation. Studies on young-of-year largemouth bass indicate that about 20-30% vegetated cover in a reservoir was optimal for survival (Durocher *et al.* 1984, Dibble *et al.* 1996, Maceina 1996). In the absence of other data, this quantity of structural complexity could serve as a crude indicator of how much total habitat is required to realise reservoir-scale improvements to a fishery.

The total amount of habitat required will depend upon the size of the reservoir and the extent of existing structure. It has previously been suggested that adding sufficient structural habitat to large reservoirs would be impractical (Miranda & Pugh 1997). It was estimated that more than 11,000 trees would need to be added to a barren 40 hectare reservoir to provide only 5% habitat coverage

(Walters *et al.* 1991). Habitat enhancement projects at Table Rock Lake and Lake Havasu have demonstrated that habitat enhancement structures can be installed in sufficient quantities to alter fisheries in even large reservoirs. At Lake Havasu, more than 135,000 pieces of habitat structure covering 1,410 hectares of reservoir have been added since 1992. There has been a remarkable improvement in the lake's recreational fishery and approximately 1,000 additional brush piles continue to be added each year for around $25,000 (USD). At Table Rock Lake, approximately 2,500 habitat structures were added since 2007 and combined with watershed remediation has resulted in noticeable improvements of the recreational fishery. These efforts achieved great results, partly because there was already natural fish habitat in the reservoir. The habitat enhancements supplemented the natural habitat to the point where sufficient critical mass was created to achieve detectable results. Based on these projects, it therefore should be possible to achieve significant improvements in Australian reservoir fisheries through habitat enhancement if sufficient resources were to be available.

Some of the specialist equipment used to deploy habitat structures: the flat-deck habitat barge and tractor at Lake Havasu, and the tilt-deck habitat barge at Table Rock Lake.

The transport and deployment of structures is not only hastened, but sometimes only possible using specialized machinery. Specialist equipment such as barges, dredges, tractors, excavators and heavy machinery needs to be utilized to efficiently introduce habitat structures at a large scale. The Lake Havasu Fisheries Improvement Program utilised two specialist habitat barges to deploy brush piles and other structures. These 13.2 metre long pontoon-hulled barges contained a large, flat foredeck onto which multiple structures and brush piles could be loaded and deployed from. The size of the barges meant that more time could be spent deploying habitat than transporting it from staging points. These barges and the tractor used to load them have been critical in getting the huge number of habitat structures into the reservoir. Shimano also donated the use of one of their specialty boats to help deploy underwater habitat. In Missouri, several specialist habitat barges have been built to deploy habitat into reservoirs. Two barges were donated by Bass Pro and Tracker Boats as part of the Table Rock Lake National Fish Habitat Initiative. The 30-foot pontoon boats were equipped with several features to assist habitat placement, including a hydraulic dump bed capable of lifting over two tons of materials and a heavy-duty winch. These habitat barges are now shared by reservoir managers from across the state and enable habitat enhancement to occur in other reservoirs at a scale that would otherwise be unachievable. Despite the size and carrying capacity of these barges, even larger and sturdier vessels are required to dump rocks and gravel. At Table Rock

Lake contractors were hired to deploy these materials. The barge used contained a parabolic tray on the front deck with a hydraulic ram to slowly push the rock forwards and off into the water. Tilt barges are not suitable for this type of work due to the sudden shifts in weight as heavy items slide off the tilted ramp. Other state agencies also have a variety of barges around the 10-13 metres length that are used for habitat deployment.

If large scale habitat enhancement is to occur in Australia then serious consideration needs to be given to the acquisition of specialist equipment such as habitat barges. These vessels could be used for multiple projects and the initial purchase and maintenance costs shared. Sponsorship or the donation of a habitat barge could be sought from key industry representatives or stakeholders, as has occurred successfully in the USA. The vessel needs to be large enough to carry and deploy significant quantities of habitat, but remain small enough to still be trailerable. This will ensure the barge can be cost effectively used in multiple locations.

Dealing with water level fluctuations

Many Australian impoundments periodically release large amounts of water for irrigation which can lead to significant fluctuations in water levels. How to undertake effective habitat enhancement in reservoirs or impoundments that have large water level fluctuations was identified as one of the top five priorities for research in Australia in the survey of researchers, managers and other stakeholders undertaken as part of this fellowship. The major concern was that the water level fluctuations would result in habitat enhancement structures regularly being exposed to air and the wetting and drying cycle would lead to rapid deterioration of structural integrity. Additionally concerns were raised regarding the enhancement structures become navigational hazards as water levels dropped.

The USA fisheries biologists share these concerns; however water levels in most USA reservoirs are typically more stable and the problem is less common. Several approaches have been used to improve the effectiveness of habitat enhancement when water levels fluctuate significantly. The simplest approach is to focus fish habitat enhancement efforts in reservoirs where the water levels are relatively stable. There are numerous reservoirs that need enhancing in the USA and resources are limited, so the initial focus has been to improve the fisheries in easier to manage reservoirs where significant benefits are more likely to be achieved.

In reservoirs with fluctuating water levels, several strategies have been utilized in the USA. The most common strategy has been to construct lines of habitat at an angle to the shoreline and covering a variety of depths. This ensures fish have access to suitable habitat regardless of the water level. In Oklahoma, brush lines and chains of other structural habitat are created along the shoreline stretching from the high water level mark to deeper water. This accommodates fluctuating water levels by providing structure at a range of depths and enables fish to move along the structure as water levels vary. Brush lines and other structures work best with hardwood timber because the structures nearest the shore experience wetting and drying cycles as the water levels fluctuate. The hardwood is more resistant to deterioration than softer timbers so will last longer. If only a limited amount of hardwood is available then it should be utilised at the shoreward end where it will be exposed more frequently. Even with the use of hardwood, timber structures periodically exposed to the air will deteriorate faster than if they remain fully submerged, so replenishment will need to be conducted more regularly than for fully submerged fish habitat structures.

In Missouri, a similar strategy has been implemented by creating rock and rubble reef lines constructed perpendicular to the shoreline. The rock is far more durable and relatively unaffected by periodic exposure to air so the reef lines are permanent structures which require minimal ongoing maintenance. The majority of the reef structures can be created by machinery when water levels are at their lowest. The deepest sections may need to be deployed by barge. These structures are located away from regular boat traffic to avoid becoming a navigational hazard, but are not marked with buoys because the policy in that reservoir is not to use buoys for installed habitat.

In Nebraska sloping breakwaters are used during reservoir re-engineering when water levels are predicted to fluctuate. Sloping refers to a perpendicular style of breakwater where the structures top height decreases with increasing distance from shore. These structures are often placed in "fields", which consists of individual rows 0.5-1.5 meters tall and 3-5 meters wide, with spacing determined by fetch angles and slope steepness. In these situations the shorelines are typically quite steep and provide poor access to heavy machinery. Perpendicular breakwaters can also be used in a similar manner, but significantly more rock is required therefore sloping breakwaters are a more cost effective option.

I believe that a combination of different habitat structures could be used to create lines of habitat in Australian reservoirs. Durable habitat made from rock or UV stabilised plastics (e.g. PVC) could be used in the section of shoreline that is frequently exposed to air, whilst other less durable habitat structure could be placed below the low water line where they are permanently submerged. This approach would ensure habitat structures last long enough to be beneficial as well as provide a greater variety of structural diversity for fish to utilize.

Another option for creating habitat in reservoirs where the water levels fluctuate substantially would be to utilise floating attractant structures. Suspending the habitat structures from floats enables them to remain at a constant depth regardless of the water level. This strategy was attempted in Oklahoma, but concerns over the structures being navigational hazards and the potential for litigation if someone were to strike them, resulted in the floating habitats being removed before their effectiveness could be properly assessed. Given that many Australian impoundments already have numerous buoys and other floating markers, I believe this strategy has the potential to be effective without increased fear of litigation. If the float is large enough, clearly marked and has solar light on it, it should not be a navigational hazard. Reduced speed limits could be put in place in areas with floating fish attractors to further avoid collision by boats. An anchored floating fish attractor structure set over a reef or other sunken habitat in deeper water could effectively attract a variety of fish species throughout the year and over changing water levels.

In reservoirs where water levels fluctuate significantly, improving fisheries productivity through the use of vegetation is difficult. The standard approach of installing beds of aquatic vegetation cannot be implemented because the plants are unlikely to survive rapid water level declines and prolonged exposure out of the water. Two approaches have been used in the USA to overcome these problems. Planting more mature root stock of emergent plants that can tolerate periodic exposure and inundation can help establish aquatic habitat. As water levels recede the vegetation is planted in areas where the tops of their stems will be just above the surface at standard high water level. The plant then has time to establish as water levels recede prior to the next flooding event. This process may take several years for the vegetation to become well established and provide adequate fish habitat. During this time there is a risk poor rainfall may lead to suboptimal water levels in the reservoir resulting in loss of the planted vegetation. The most effective plants in the USA have been water willow *(Justicia americana*) and buttonbush (*Cephalanthus occidentalis*). Native plant species could be found in Australia to fulfil this role. Additional benefits of introducing aquatic vegetation include the potential reduction in erosion and addition of nutrient to the aquatic ecosystem as the plants decay.

Emergent plans have been planted and established during a period of low water level. It takes several years before the plant coverage becomes extensive (images TPWD)

The establishment of annual vegetation on the exposed shores during low water levels has also been found to be an effective technique for improving fish habitat and increasing productivity in reservoirs with seasonally fluctuating water levels. Sowing grass and other plants on exposed reservoir slopes creates vegetation which becomes inundated when the reservoir next fills. This vegetation not only provides habitat for fish, but also introduces additional nutrients into the water as the plants decay. Some reservoirs are nutrient deficient and this nutrient boost leads to increased productivity, producing similar effects to those experienced after initial flooding. The inundation and decay process is similar to what happens when a reservoir is first flooded following construction and leads to the period of highest productivity in a reservoirs lifespan.

Comparison of the effectiveness of habitat enhancement techniques

One of the key questions regarding fisheries habitat enhancement is how effective different structures are at attracting fish or improving impoundment productivity factors. The principal role of most installed habitat structures is to aggregate fish for anglers to increase their catch. The consensus in the USA was that in the absence of other habitat, all fish habitat structures will attract fish, but the relative effectiveness will vary between structure types and fish species. There is a lack of data directly comparing the effectiveness of most habitat structure types. Habitat structures are frequently installed in mixed arrays and surveys of the fish response are not at a fine enough scale to identify the contributions of each structure type.

The use of artificial materials to construct habitat structures has become far more common as waterway managers worry about the impacts on water quality from decomposing organic materials. It is well accepted that habitat structures made from synthetic material are more durable than those made from brush and timber. However it is less clear whether the synthetic structures are as effective at attracting fish compared to fully intact natural material structures. Research results and opinions are still divided on the issue.

In North Carolina, a three-year fish study by North Carolina Parks and Wildlife Commission evaluated the effectiveness of half-barrels, Georgia cubes, Porcupine Balls™ and bundles of evergreen trees; in terms of how well they concentrated fish and their durability over a three-year period (J. Baumann pers. com). During the first two years, all structure types held similar amounts of fish and more than the bare control sites. However, by the third year, all three artificial structures held more fish than the evergreen bundles, which had lost all of their needles and were nothing more than trunks and a few major branches. Of the synthetic structures, the Georgia cubes held the most fish during the third year. The study concluded artificial structures constructed from synthetic materials were much better at attracting and holding fish over a long period of time than structures made of natural materials and did not need replenishment.

A Porcupine Ball™ fish attractor used in the North Carolina study by Jessica Baumann and her colleagues (image NCWRC)

A study comparing natural brush and synthetic structures in Florida reservoirs found plastic and brush structures concentrated similar numbers of fish, but largemouth bass were more frequently caught angling on the plastic attractors (Thompson 2015). Warm productive water in Florida quickly breaks down natural brush and necessitating frequent refurbishing. The authors concluded synthetic fish attractors may be a long-term and useful tool for fisheries managers looking to supplement declining/degraded habitat in reservoirs and lakes where natural brush quickly decomposes.

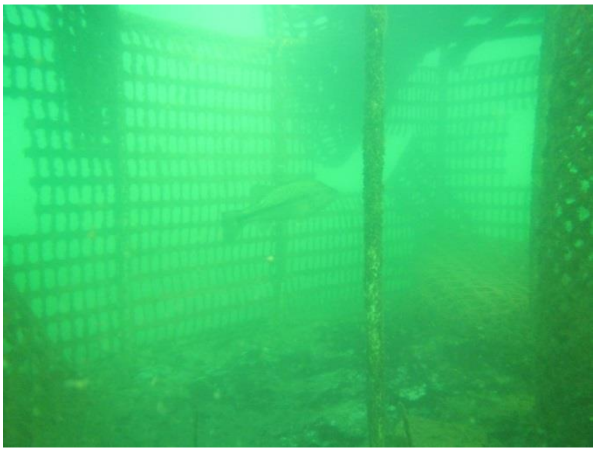
Conversely, other research indicates that natural structure is more effective at attracting fish species targeted by anglers. Texas Parks and Wildlife Department compared the fish attracting ability of plastic pipe structures to juniper trees (Mahnelia *et al*. 2008). Overall, far fewer fish were observed in the plastic attractors compared to juniper tree attractors. Juniper attractors concentrated 10 times more adult and juvenile largemouth bass and bluegill compared to plastic attractors. The authors concluded that “although fabricated plastic fish attractor designs are desirable because of their longevity, their effectiveness for attracting and concentrating target species should be evaluated prior to being used in large scale projects”. Similar results were also observed in Kentucky where 78% of observed fish used the natural materials compared to only 17% using the plastic module attractors and 5% in control areas (Rold *et al.* 1996).

Johnson and Lynch (1992) compared fish use of a range of timber habitat structures such as vertical and prone evergreen trees, a brush pile, and stake beds. Evergreens attracted more bluegill, but no differences were observed for white crappie use. However, anglers were most successful for both of these species when fishing at the evergreen trees. The authors concluded that evergreens were the cheapest and most effective structure to install, but stake beds should be avoided because they were expensive to build and yielded poor angler catches.

I was lucky enough to be able to SCUBA dive on habitat structures in Table Rock Lake, Missouri and Lake Havasu, Arizona. These dives were very informative and enabled me to observe fish responses to a range of different habitat types and on structures that had been deployed for different periods of time. Unfortunately the visibility in Table Rock Lake was extremely poor (<1.5 metres) due to the recent passing of a hurricane, but the water in Lake Havasu was much clearer (4-5 metres). In general, the number of fish using a structure was higher for brush than other habitat types. Small largemouth bass and sunfish were highly prevalent on brush structures. Up to four year-classes of bass were observed on some brush piles, with the smaller fish holding tightly to the structure and the larger fish circling further out. Palm frond bundles typically held only a few smaller fish. The habitat constructed from plastic and snow fence held the least fish, but these fish were generally of larger size. This was more pronounced where the plastic structures were located in isolation and not near any brush. Several large flathead catfish and largemouth bass were found in this situation. Where PVC structures were located adjacent to brush piles many more small fish were observed.

Habitat structures containing smaller, denser interstitial spaces tend to hold a greater abundance and size range of fish

One observation worth noting was that structures with smaller interstitial spaces such as brush piles and sunken trees tended to hold greater species diversity, a greater number of year classes and more forage species. The general feedback that I received from many of the fisheries biologists in the USA was that the denser the structure is, the more fish that are attracted and held by it. If the objective is to provide habitat for smaller fish and juveniles of larger species, habitat structures must have a variety of interstitial space sizes. Few of the plastic habitat structures have small interstitial spaces due to the component materials and design. Research into designs with reduced interstitial spaces may lead to more effective attraction of a wide range of size and species of fish, and particularly provide benefits to juveniles. However, more open structures appears to attract larger fish which are what anglers generally prefer to target and are less likely to get snagged by hooks. A combination of different habitat structure designs is most likely to have the broadest benefits.




Note the low number of fish using these open structures. These structures tend to be dominated by 1 or 2 large fish only.

There remains little doubt that brush structures are effective at attracting fish. Questions comparing the effectiveness of brush to solid timber, rock and plastic fish habitat inevitably focus on long-term effectiveness and durability. Is there more long-term benefit in installing more durable structures which in some cases may not attract as many fish, or is brush so much more effective and cheap to deploy that it should continue to be utilised and refurbished? Unfortunately few long-term studies have been conducted in enough detail to answer this question and the strategy chosen will be dependent upon the characteristics of the individual reservoir, permitted activities, water temperature, material availability and volunteer labour. Several of the pine trees/evergreen Christmas tree bundles I observed which had remained permanently submerged remained in good condition 5 years post installation. No leaves or needles were left however most of the lateral branches remained intact. The best results were observed when the trees were bundled together prior to sinking to create larger brush piles and more complex habitat. In areas with cooler water temperature brush structure is likely to persist for longer and therefore be better value.

Hard structure and rock has also proven to effectively increase local fish populations and angler catch rates if installed in sufficient quantities. Again I could find no studies comparing the effectiveness of rock to other habitat structure types. In Lake Erie, twelve 1-2 metre high rock piles had negligible impact on fish populations, but when additional larger reefs approximately 250 metres long and 2-4 metres tall were created, a wide variety fish species and more anglers were attracted (Kelch *et al.* 1999). The additional structure resulted in 20-50 times more fish at the reef than at control sites. In Lake Michigan, construction of a large limestone reef attracted a large number of different species and increased angler catch (Binkowski 1985).

Re-establishment of aquatic vegetation in reservoirs was also found to be an effective approach to improve the fishery but took a long time. It would be difficult to compare restoration of aquatic vegetation directly with other habitat enhancement types. Typically fish attraction structures are also used at low densities when aquatic vegetation projects are undertaken. The concept seems to involve using the vegetation to improve the fish population and the attractors to aggregate fish to improve angling catch. In all reservoirs where sufficient vegetation was established, significant increases in angler catch rates were observed (e.g. Lake Athens (Norman & Ott 2014), Lake Conroe (Webb *et al.* 2014)). Natural recruitment, juvenile survival and the abundance of forage species often increased, leading to larger and more stable sports fish and panfish populations (Wiley *et al.* 1984, Norman & Ott 2014). However, not all studies have had positive results. Hoyer and Canfield (1996) found no strong predictable relationships between the abundance of aquatic macrophytes and the abundance of adult largemouth bass among Florida lakes greater than 300 hectares. The rehabilitation of aquatic vegetation also provides a broad range of other ecosystem benefits and therefore is always likely to be beneficial. Planting grasses and other vegetation during water drawdowns has also been demonstrated to be beneficial to sports fish and panfish populations (Miranda *et al.* 1984, Ratcliff *et al.* 2009, Beal et al. 2010). A growth study by Ratcliff (2006) indicated that black bass held in an enclosure with grass did not grow significantly larger than those in control sites, suggesting grass may serve a greater role as cover for juveniles than food production.

Completely re-engineering a reservoir has proven to be the most consistent method to increase reservoir productivity and improve failing fisheries. Positive results have occurred in almost all such projects undertaken in Nebraska, Pennsylvania and Oklahoma. It is impossible to compare the effectiveness of this technique to the installation of habitat enhancement structures and vegetation management because these other techniques often form an integral part of the reservoir reconstruction. This integrated approach is likely to provide the most effective long-term improvements in reservoir fisheries, but may only need to be undertaken in highly degraded systems.

Monitoring and evaluation of habitat enhancement activities

The use of habitat enhancement to manage reservoir fisheries is not a new science; however the outcomes of intervention activities often remain unclear. Knowledge on the benefits habitat enhancement provides under various conditions is essential for developing workable management strategies. Monitoring the impacts of habitat enhancement activities is vital to determine if project objectives are being met, as well as providing valuable information for optimising future projects. The suite of factors monitored is guided by the specific project objectives, identified knowledge gaps and available resources. Monitoring should not be restricted to the biological system, but also include angler data, structure condition, economic response and social impacts.

The inclusion of pre and post-enhancement surveys should be considered a fundamental part of the planning process. Baseline surveys provide detailed information on the status of the reservoir prior to the commencement of enhancement activities and form the basis against which the success of a project's objectives can be determined. Baseline surveys also provide data to identify the remedial actions necessary to achieve the project objectives. For example, if the baseline survey identifies significant amounts of existing structural fish habitat in a reservoir, then it is unlikely that the addition of further similar habitat will have a significant impact. Conversely if structural habitat is limited, then the installation of this habitat type could be a priority. Where possible, before and after surveys should be conducted over multiple years or periods to provide more detailed data and cover unusual environmental conditions or events. Incorporating multiple survey periods also provides data on trends rather than an instantaneous snapshot at a particular point in time.

Monitoring the fish population response

Detecting a response in the fish community at the reservoir scale is extremely difficult. The large physical size of most systems and the number of potentially confounding factors generally necessitates the use of more than one technique. Absolute changes may not be detected by a single survey technique; however combining the data from multiple techniques can often provide enough evidence to draw conclusions with reasonable certainty.

Historically, fish communities in USA reservoirs have generally been surveyed using gill nets, trap nets and electrofishing. These techniques are well established and the data widely accepted by managers and the scientific community. Gill nets can be very effective at surveying fish populations but are the most destructive of normal biological sampling methods. The major advantage of gill nets is that they are effective regardless of the water depth and can sample a wide size range of fish if panel or trammel designs are used. Gill nets are one of the few effective techniques for sampling fish in deep water. Trap nets have also been frequently used in the USA. A wide range of trap designs have been used to target a range of fish sizes in a variety of water depths. For traps to be effective the fish must be mobile and willing to leave their cover to enter the trap. Movement rates can vary with environmental conditions or seasonally, so long-term data sets are necessary. Electrofishing is one of the most commonly used reservoir fisheries techniques, but is restricted to shallow water depths (<5m). The technique provides an instantaneous snapshot of the fish community and works effectively on all sizes of fish. Electrofishing is effective at estimating fish abundance from within habitat structures, but slightly less successful in open water where the boat can scare away fish. A combination of electrofishing and netting is the most common approach used in the USA to conduct before and after surveys of reservoir fish communities.

A range of strategies have been used to conduct visual surveys to determine the fish response to habitat enhancement. The general consensus amongst the fisheries biologist I met during the Churchill Fellowship was that these techniques were ineffective at providing long-term assessments for habitat enhancement. Visual counts using SUBA divers, underwater cameras and time-lapse photography were highly confounded by underwater visibility and cryptic fish behaviour. Data from these techniques was found to be inconclusive due to high variability between counts and the techniques are longer used for periodic fish surveys, even in clear lakes.

Angling surveys have been trialled to assess the fish community response to habitat enhancement. Standardised angling efforts were applied periodically to look for changes in the composition and abundance of fish species captured. A large number of factors such as weather, season, angler skill and water temperature can confound data from surveys conducted in this manner. Most fisheries biologists have moved away from this technique for these reasons as well as the difficulty in getting adequate angling pressure in specific areas to provide sufficient data for analysis.

One of the newer and more technologically advanced techniques employed to evaluate fish populations involves the use of hydro-acoustics or sonar. When compared to other commonly used fish sampling techniques hydro-acoustics provide a non-invasive and logistically feasible sampling method for deeper water applications. Sonar also enables surveys to be conducted in turbid water where visual counts would not be feasible. In recent years technological improvements in the ability of echo-sounders to discriminate small objects has improved significantly whilst the cost of quality units has also decreased. Sounders are often be used to detect fish in open water environments, but more advanced units will also detect larger fish amongst habitat structures. It is usually not possible to identify fish species or length using hydro-acoustics alone, but better units can clearly discriminate fish of different sizes and enable biomass estimates. It is recommended that sonar images be corroborated with another sampling method to determine the composition of the fish community. Sonar systems can use single frequency transducers commonly found on most boat units or multi-frequency systems like the DIDSON (Duel-Frequency Identification Sonar). Multi-frequency systems provide more detail but are more expensive and logistically more difficult to operate.

The use bio-telemetry to track fish movements would provide a more detailed understanding of fish use of habitat structures. Unlike radio-tracking, modern acoustic tracking equipment has the ability to track three dimensional fish movement and can be deployed to track fish for long periods of time with minimal labour. Acoustic tracking provides continuous information on the location of the fish and would detect diurnal and seasonal use of habitat structure and patterns of movement. Comparison of the use by fish of multiple habitat structure types could be achieved by installation of listening arrays around the structures and monitoring the time spent by fish in each habitat. This would help identify the preferred habitats, and those which were less effective and could be replaced by other structures. It is strongly recommended that initial reservoir habitat enhancement projects in Australia utilise acoustic tracking to determine the most effective habitat enhancements to install in reservoirs.

Monitoring angler success

Directly measuring changes in the fish community is often difficult and the results frequently inconclusive. However, the management objectives of most reservoir habitat enhancement projects normally include improvements in angler catch and satisfaction and changes in these can be readily assessed using angler creel surveys. This information has frequently been used to identify direct benefits to anglers and validate the costs of habitat enhancement projects in USA reservoirs.

Before and after angler creel surveys can provide quantitative data on changes in species composition, fish size and abundance, harvest rates, angler success, visitation rates, use of habitat structures, fishing pressure and economic expenditure. The data can be used to identify the angling attributes that have benefitted the most from habitat enhancement and those which have not improved. This feedback enables management strategies to be adapted to address any deficiencies and identify successful strategies for future projects.

Creel surveys should be carefully structured in a similar manner to that used for fish communities with multiple before and after surveys. Differences in angler use and target species at different parts of large reservoirs needs to be considered. Excellent examples of such surveys were undertaken in Table Rock Lake (Allen *et al.* 2014) and Lake Havasu (Anderson 2001), and following these methods will produce reliable and informative data.

Monitoring the condition and durability of habitat structures

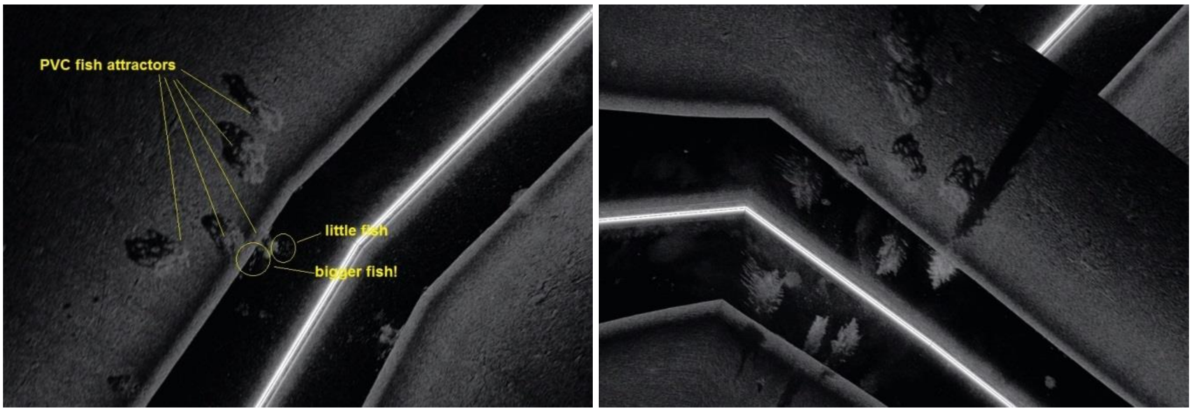
It is also important to monitor the condition of the habitat enhancement structures that have been deployed to determine whether they need maintenance or replacement. Structures made from brush and timber degrades over time and monitoring their condition will inform when replenishment or replacement is necessary to maintain their attractiveness to fish. Accurate condition assessment will enable the habitat in a reservoir to be most cost-effectively managed. Plastic structures are less likely to deteriorate over time, but monitoring helps identify structures which are damaged or missing.

There still remain many knowledge gaps regarding the attractiveness and persistence of different habitat structures. Monitoring the condition of installed structures will provide additional data to assist in determining the most cost effective habitat enhancement strategies. Combining knowledge on changes in the fish community with data on the available habitat structure will improve our understanding of the longer term impacts of reservoir enhancement projects.

There are several methods used to assess introduced fish habitat condition. Inspection by SCUBA divers is the most labour intensive methods, but also provides the most information. Condition assessment is far less dependent upon underwater visibility than fish counts, so the data collected is more reliable and less biased. In Lake Havasu, teams of professional divers work in pairs to assess the condition of fish habitat structures once a year. Not all structures are inspected every survey period due to the massive amount of habitat installed. Instead a random selection of individual structures or areas is chosen and surveyed.


Divers assess the condition of habitat structures in Lake Havasu (images BOR Lower Colorado Region Dive Team)

Habitat condition can also be assessed directly from a boat. In areas with relatively clear water it may be possible to assess habitat structure condition by lowering a camera down near the structure and record footage as the camera is moved around. Sonar can also be very effective at examining habitat condition. Many newer boat sounders have the capability of providing excellent quality images of underwater structures. Images of each structure could be captured and stored to provide a record of structure change following installation. This method would be extremely quick and easy and is not reliant upon water turbidity. An advanced version of sonar assessment was employed in Piedmont reservoirs by North Carolina Wildlife Resources Commission to monitor the durability of four different structure types (Baumann 2014). DIDSON was used to capture detailed images of the different habitat types over a 3 year period. The level of detail was sufficient to clearly identify the deterioration rate of evergreen tree bundles.



Screen shots from a high quality side-scan sounder showing PVC and pine structures (images TPWD)

The level of detail possible with sonar images lends this form of condition monitoring to broader use. In Australia many fisheries boats, and even boats belonging to recreational anglers, have sufficient sonar systems for habitat condition assessment to be undertaken with little additional resourcing. One of the other applications of modern sonar is for baseline surveys to identify underwater habitat structures prior to commencement of an enhancement program. The side-scan features on many newer sounders can capture structure in wide swaths either side of the boat. Software can then be used to link these images together to form an image of the underwater topography of the reservoir. This can be used to identify where existing structure occurs and areas where the structure could be supplemented.

Monitoring social impacts

One of the less common forms of monitoring employed during habitat enhancement projects involves looking at social changes. The value of human dimensions research is often overlooked. Monitoring and evaluation plans rarely have a human dimensions component, and if they do it is often a small retrospective project. The ultimate objective of reservoir fisheries enhancement is to improve the angling experience in a sustainable manner. Monitoring the satisfaction levels of anglers provides direct feedback on whether this has been successfully achieved. The most powerful data comes from the comparison of attitudes of anglers and the broader community before and after management activities are implemented. This can be monitored directly through surveys or indirectly through the social media. A clear understanding of community attitudes will reflect uptake and support for a project and monitoring can be used to identify the impact of extension efforts and direct where it needs to be targeted. Disillusioned or disenfranchised anglers will make it difficult to complete large scale projects. North Carolina Wildlife Resources Commission believes they could improve the amount they work with anglers to get a better angler perspective and more satisfied anglers.

Monitoring economic impacts

Monitoring and assessment of the economic benefits and cost-effectiveness of habitat enhancement is rarely undertaken adequately. One of the key criteria for funding application, and the level of investment and support that a project receives, is the expected economic returns. In reservoir habitat enhancement this is not easy to quantify because the benefits are triple-bottom-line: there are social, environmental and economic benefits to reservoir fishery restoration and improvement. Developing economic benefit scenarios at the commencement of a project can be extremely powerful in attracting investment. For example, as part of the Lake Wichita Revitalisation Project the economic impact assessment of the planned remedial works estimated that upon completion the annual economic value of the project to the local community would be in excess of $300 million per year (Martinez 2015). The investment needed for the project is only $55 million; therefore it is defensible to argue that the funding would receive an excellent long-tern return on investment.

The most effective method for generating economic impact assessments is often through the comparison of before and after data. Unfortunately, many projects have limited economic data for reservoirs prior to commencing fisheries enhancement activities. When data is available it can be outdated by several years or collected for other purposes and thus not contain the required details. Collection of baseline economic data should form a critical component of any monitoring and evaluation plan for reservoir fishery enhancement. Some of the data required is already captured in state or nation-wide angler surveys; however these may not accurately reflect travel costs at the local level for a specific reservoir.

Robust data on the costs of using different habitat types is also necessary to assist the reservoir habitat enhancement planning process. Not all projects keep detailed records of the construction and deployment costs for different habitat types. Where this data has been collected it has not always been readily accessible. Pooling this type of data and the associated changes in a reservoir fishery will enable the cost-effectiveness of different habitat enhancement strategies to be calculated and lead to more informed decision making during project planning.

Funding and management models

The funding model for fisheries management and research differs greatly between the USA and Australia. In the USA, funding for reservoir fisheries management and research is far more substantial. In most states a licence is required to fish in freshwater and the revenues collected go to managing and improving freshwater fisheries. Some states in Australia already follow this model and these typically have greater levels of management resources.

However, the greatest difference in funding comes from the USA Sports Fish Restoration Act (1950), otherwise known as the Dingell-Johnson Act. This piece of legislation provides Federal aid to the States for the management and restoration of recreational fisheries, aquatic education and wetlands restoration. Funds are derived from a 10-percent excise tax on certain items of sport fishing tackle, a 3-percent excise tax on fish finders and electric trolling motors, import duties on fishing tackle, yachts and pleasure craft, interest on the account, and a portion of motorboat fuel tax revenues and small engine fuel taxes authorized under the Internal Revenue Code. Funds for the states sport fish programs are apportioned on a formula basis for paying up to 75 percent of the cost of approved projects. Eligible projects include acquisition and improvement of sport fish habitat, stocking of fish, research into fishery resource problems, surveys and inventories of sport fish populations, and acquisition and development of access facilities for public use. No such tax or revenue system exists in Australia, but if ever implemented would revolutionise fisheries management in Australia. The funds collected by the Sports Fish Restoration Act are directly applied to improving reservoir fisheries through habitat enhancement and are critical in enabling large-scale projects to occur.

"The task of restoring habitat in the nation's reservoirs is a multi-jurisdictional challenge and cost prohibitive for a state and/or federal agency to accomplish without partnering with other public and private organisations or individuals." *Jeff Boxrucker, Reservoir Fisheries Habitat Partnership, November 2015*

At the state and reservoir level, project funding sources can vary greatly. For example:

- In North Carolina funding for reservoir habitat enhancement is typically evenly divided between the Federal Sport Fish Restoration Program, State license fees and direct funding through the Wildlife Resources Commission.
- At Table Rock Lake, Missouri, project funding was sourced from State, Federal and private sector sources.
- The Lake Havasu Habitat Improvement Program was funded by a combination of contributions from the various partners. The Bureau of Land Management arranged for federal funding to pay for one half of the annual costs and the other six partners agreed to contribute the other half, contingent upon budgetary availability (Jacobson & Koch 2008).
- An aquatic habitat stamp was added to angling license fees in Nebraska to meet the rising cost of aquatic habitat rehabilitation. Revenue from the stamp is used to fund the Nebraska Aquatic Habitat Restoration Program who are tasked with enhancing and restore aquatic habitat and angler access. Their goals are to improve recreational angling in Nebraska's rivers, lakes and reservoirs and create sustainable fisheries.

Community or volunteer groups generally cannot significantly contribute financially to a project, instead supplying volunteer labour. The level of volunteer labour contributions can be significant and a major factor in the successful completion of many projects. During the initial 10 years of Lake Havasu Fisheries Improvement Program, volunteers provided more than 170,000 man-hours of time and were critical in all aspects of the habitat program. It is important that volunteers receive clear communication, direction and empowerment to ensure long- term

An example of the aquatic habitat stamp used in Nebraska to generate funding for aquatic habitat improvement projects

involvement. Their efforts should be recognized and rewarded to show appreciation for their involvement. For example, at Lake Havasu the program holds a monthly hot dog day for volunteers and landscapers who supply the brush to make the structures. This relatively cheap event re-enforces the volunteer's feelings of value to the project and helps build teamwork and comradery.

The governance models for reservoir fisheries projects in the USA varied greatly, but were not dissimilar to comparable resource management projects in Australia. Smaller projects were often run entirely by State fisheries or wildlife management agencies, with input from key stakeholders. Larger projects typically had a more formal governance structure in place and involved a number of partners. Memorandums of understanding were used to formalise the role and contribution of each project partner. Larger projects established steering committees consisting of key stakeholders to make strategic and logistical decisions and assist liaison between staff of different organisations. Anglers were typically represented by local angling clubs or state affiliates. Waterway managers were always offered a place on the steering committees as they typically set the regulations for what activities could and could not be undertaken in a particular reservoir. State fisheries biologists were included in all steering committees to provide technical advice and direct research and monitoring activities. The steering committees met regularly to discuss work progress, funding and resource issues and vote on major decisions.

The Lake Havasu Fisheries Improvement Program utilised a more complex governance structure due to its extensive scale, significant funding and multiple government partners. The structure of the partnership was established by a memorandum of understanding and consisted of an Executive Committee that made key program decisions and a Technical Committee that assured quality control and developed management proposals (Jacobson & Koch 2008). The Executive Committee consisted of agency directors or their representatives and met at least once a year. The Technical Committee served at the direction of the Executive Committee and comprised experts appointed from within the partner organisations. The role of the Technical Committee was to provide recommendations and options for implementation of the program objectives they met on a quarterly basis. Inter-agency and co-operative agreements, cost sharing, and pooling of expertise and resources allowed the program to run efficiently.

Small habitat enhancement projects in Australia should be able to be run entirely by State fisheries or wildlife management agencies, with input and assistance from key stakeholders. Larger habitat enhancement projects will most likely involve multiple partners and thus should include a steering committee comprising representatives of key stakeholder groups as part of their governance model. The steering committee will ensure the project benefits as many of the stakeholders as possible, make strategic and logistical decisions and assist liaison between staff of different organisations. There is potential to for habitat enhancement programs to develop in some larger impoundments, such as Wivenhoe and Somerset Dams in Queensland, if significant community and volunteer support is achieved. The labour costs for constructing and deploying sufficient habitat in larger Australian waterways will be prohibitive if fully costed. For projects to occur in these waterways significant volunteer labour will be required. Once a project is established, the ongoing cost of constructing, deploying and maintaining habitat structures should be low if undertaken primarily by the volunteers. Ideally the role of state fisheries agencies should be to provide technical advice and oversight.

Case studies

This section presents six case studies which provide excellent examples of the benefits that can be achieved from different habitat enhancement activities. These techniques could be applied in Australia to potentially deliver similar results.

Table Rock Lake, Missouri

Table Rock Lake is an excellent example of how a failing reservoir fishery was turned into one of the best lake fisheries in the USA. Much of the following information is derived from discussions with Shane Bush (Missouri Department of Conservation), Stacey King (professional tournament angler and fishing guide), and the report by Allen *et al.* (2014) on the first six years of the National Fish Habitat Initiative project in the lake. For more details see the full report and the interactive habitat website set up for Table Rock Lake.

Description

Table Rock Lake is located in the Ozark Plateau along the Missouri-Arkansas border and is located on the junction of the James and White Rivers. Table Rock Dam was constructed in 1958 primarily for flood mitigation and hydro-electric power generation. At conservation level, the lake encompasses 17,450 hectares with 1200 kilometres of shoreline. The reservoir is up to 67 metres deep, with an average depth of 21 metres. Table Rock Lake is typically quite stable and fluctuates slowly, but can have seasonal fluctuations of up to 4.5 metres, although more usually only 3 metres. With the depth of the lake and the surrounding shoreline of bluffs, rocks, and gravel, and relatively devoid of aquatic macrophytes, the water in Table Rock Lake is relatively clear most of the time. When the dam was initially flooded some of the trees were left standing in the lake, with the predominant tree being the cedar. These have now deteriorated with age. The lake has reasonable shore habitat but lacks structure away from the margins.

Table Rock Lake is now acclaimed as one of the top bass fishing lakes in North America and holds excellent numbers of largemouth, Kentucky and smallmouth bass of exceptional size. Crappie, bluegill sunfish, walleye and paddlefish are among the other primary sport fish in Table Rock; however, black bass receive the most attention and fishing pressure. Many fishing tournaments are held on the lake each year, most of them relatively small (20+ boats), but there are also several major professional events (150+ boats) offering huge prize money (up to $250,000 for 1st prize!). Most days there are up to 100 boats, although this number increases drastically during spring. The combined annual economic benefit of angling on Table Rock Lake and Lake Taneycomo (downstream) is conservatively estimated at $67 million (Vitello & Armstrong 2008).

Issue

Typical of an aging reservoir, there has been a precipitous decline in the abundance of fish habitat in Table Rock Lake since its impoundment (Allen *et al.* 2014). Much of the landscape that was flooded to create the reservoir consisted of Ozark highland forest. As the reservoir began to fill rapidly, it was not possible to fully harvest trees and the remaining forest stood high in the water column. As the reservoir aged, the "standing timber" began to deteriorate, resulting in fewer habitats available for fish in the reservoir to utilize. The lake became known as a “tough” lake for anglers to fish (Allen *et al.* 2014). To further add to the degradation of the aging reservoir, human population increases and urbanization of the Table Rock Lake watershed began to have negative impacts on the water quality of Table Rock Lake. In 2007 the National Fish Habitat Initiative project was initiated to sustain and improve the degrading physical habitat within Table Rock Lake and improve the fisheries. Table Rock Lake contained the necessary components of economic importance, heavy public use, and adequate fish densities to serve as a national model in sustaining and improving fish populations in aging reservoirs and watersheds.

Fisheries objectives

- To improve the physical habitat for fish and recreational opportunities in Table Rock Lake
- To monitor the effectiveness and longevity of structures and projects employed
- To answer questions about the effectiveness of large scale habitat restorations in reservoirs

Actions

In 2007, Table Rock Lake was chosen as the first More Fish Campaign pilot project focused on reservoir habitats and the health of their watersheds. The Missouri Department of Conservation, in co-operation with many project partners began the National Fish Habitat Initiative project to sustain and improve the degrading physical habitat within Table Rock Lake.

The Missouri Department of Conservation implemented a large scale program for improving fish habitat within Table Rock Lake and utilized several different techniques for installing the habitat. Dialogue with anglers, guides and other stakeholders was undertaken to determine the locations and types of fish habitat that would be most effective. Their ideas and input were instrumental to the success of the habitat placement. Anglers were given the opportunity to provide biologists with insight about the locations where fish could already be found and areas where habitat could improve fish holding ability.

Many different types of materials were used to create fish habitat structures. Hardwood tree tops and cedar trees were the most common types of material used to construct fish habitat, but pine (Christmas) trees were also used when available. All of the materials used were comprised of natural materials that would not pose a risk of affecting water quality. No plastic or PVC structures were permitted to be installed in the lake. The habitat structures were typically anchored using concrete weights shaped in buckets or concrete filled cinder blocks with metal hoops for attachment. Some larger trees required greater anchor weights which were constructed in formwork from concrete. The majority of materials for building habitat structures were collected from landowners, contractors, developers, and businesses who were already removing trees for management practices, timber sales, urban development, etc. This technique for collection of materials benefited all parties involved; as a means to dispose of tree tops, stumps, and rocks, and to enhance habitat in Table Rock Lake. Collecting material in this way also reduced the amount of materials to be removed from the land surrounding the lake. Only a small percentage of the habitat placed in Table Rock Lake was obtained from the shoreline. Removing trees from the shoreline in the quantities needed for this project had the potential to cause water quality and erosion issues, so strict limitations on the places where trees could be felled were instigated. The majority of structures and materials were staged on the bank before being loaded onto the barges using excavators. Where it was necessary for trees to be felled from the shoreline, it was undertaken at the closest suitable area to the installation site.

Staging weighted trees ready for loading onto the habitat barge.

Most of the habitat structures were placed in Table Rock Lake by way of boat. A large, specialist pontoon style habitat barge with a hydraulic platform mounted on the front half of the barge that could be raised from the midpoint was donated by Bass Pro Shops and Tracker Marine. The habitat barge was used to place the cedar, pine, and hardwood tree tops in Table Rock Lake. For safety reasons, this barge was not used to place the stump or rock habitat in Table Rock Lake as just one stump could have exceeded the weight limit. A separate larger barge was constructed for the project to deploy the heavier stump and rock habitats into the lake. This barge used a hydraulic piston to push the structure forward off the bow, rather than tilting the front deck.

A total of 2,024 habitat structures were placed into Table Rock Lake between 2007 and 2013. Of these structures, 1,797 were hardwood, cedar or pine trees, 76 were stump fields, 140 were rock structures, and 11 were a combination of rocks and stumps. Most structures were placed in 3.0-9.0 metres depth of water to avoid navigational issues. Additionally, 26 shallow water rock fence structures, each 15-30 metres in length and approximately 1.2 metres tall, were installed perpendicular to the shoreline during periods of low water. The location of these fences was away from usual boat traffic so they were not marked by buoys to warn of the potential navigational hazard. Additional habitat in the form of cedar and hardwood trees continues to be added to the lake each year.

A load of freshly felled cedar trees being loaded onto the habitat barge and sunk for habitat.

To improve the opportunities for anglers to use the installed habitat structures the location, structure type, installation date, depth, lake region and number of barge loads taken to a particular site were made publically available on an interactive GIS website. The website has given anglers the opportunity to locate these structures while angling on Table Rock Lake and potentially improved fishing experiences on Table Rock Lake.

Fish attractor signs were also placed on the shoreline near 100 of the habitat structures. Many tourists visit the lake annually and a large percentage of those visitors explore the lake in rental boats that may not be equipped with sufficient technologies for locating habitat structures. The fish attractor signs provide these anglers with a starting point to improve their angling experience. An additional benefit to placing fish attractor signs is to heighten awareness of the project. These signs are highly visible and many visitors stop and read these signs, therefore increasing their knowledge of fish habitat enhancement efforts on the lake.

"Habitat enhancement has made it a lot easier for tourists to come and fish and increased the likelihood of them catching something." *Stacey King, professional tournament angler and guide*.

The Table Rock Lake project was a pilot project focused on habitat enhancement and restoration in large reservoirs. Information needed to be gathered related to increased production of sport fishes, congregation of fish to specific areas, species use of different habitat types, and angler catch rates and opinions of habitat types and placement. Missouri Department of Conservation, Fisheries and Resource Science Divisions worked together to find answers to many of these matters and determined four different techniques to evaluate this project. Treatment and monitoring of standardized electrofishing coves was undertaken to monitor the ability of habitat enhancements to congregate fish to specific areas of the lake. SCUBA survey techniques were selected to monitor the effectiveness of the different types of structures to attract bass and crappie. A bio-telemetry study was done to track movements and habitat use of largemouth bass on a daily and annual basis. Finally, two angler surveys were undertaken in order to assess changes in angler catch rates and fishing pressure as a result of the installation of additional fish habitat and assess angler opinions regarding the habitat project as well as their angling success in Table Rock Lake.

Outcomes

One of the main reasons for installing habitat structures in a reservoir is to improve angling opportunities and angler catch rate. This can be achieved by increasing the number of fish in the lake or by making the fish easier to target. The Table Rock Lake project was conducted on a scale large enough to look for both increases in fish productivity and aggregation. The results of the electrofishing surveys indicated the installation of habitat structures in the lake had little impact on the overall population abundance between 2006 and 2013 (Allen *et al.* 2014). Trends in standardised electrofishing catch rate after habitat structures were installed appear to mimic those present prior to the installation. Similarly, the size of fish did not seem to increase after the installation of habitat structures. However, the installed structures did seem to attract and concentrate fish in the immediate vicinity around the structures. Installing habitat structures may improve angler catch rates by concentrating fish at the local level and the presence of these structures seems to improve anglers' perception of the fishery and improve the quality of their fishing trip.

The results from the SCUBA surveys suggested black bass used the hardwood habitat structures more than other structure types. Crappie were observed most often utilizing cedar habitat structures. Regardless of habitat structure type, all were utilized by black bass, crappie, or both at some time. Observations suggest that it can take between 6-12 months for sunken trees and brush to become optimal at attracting the most fish. Installing a range of habitat types would provide fish with a variety of different habitat options. However, cost : benefit analysis for installation of each of the habitat structure types needs to be taken into consideration. Hardwood or cedar habitat structures seem to attract both black bass and crappie were among the more cost effective habitat structures installed. Although some structures were not as effective on Table Rock Lake, they should not be discounted for other systems.

The results from the SCUBA survey and radio-tracking study by Allen et al. (2014) suggest that fish will utilise habitat deployed at a range of different depths, but their use varied seasonally. The chances of fish using installed habitat structures were equal to or greater than the chances of fish utilizing natural habitat types. Placing structures in a way that ensures they are not a hazard to boaters is important during any habitat improvement project; however, structures must not be placed too deep or they might not be utilized by fish if below the thermocline.

The information gained through the angler surveys indicated anglers support installation of habitat structures in Table Rock Lake and also believe that the installed habitat structures in the lake improved their fishing. Many anglers specifically fished the habitat structures for a variety of species. Local anglers were generally more aware of the habitat improvement project and fished at installed habitat structures more than non-local anglers. In addition, local anglers' perceptions that the habitat improvements in Table Rock Lake had improved their fishing increased by 20 percent from 2012 to 2013 and only increased 10 percent with non-locals. Anglers reported that hardwood and cedar trees were effective habitat types, but also reported that rocks and stumps could be effective at times. Anglers indicated that pine trees were by far the least effective habitat type installed.

Overall, the project and ongoing installation of additional structures (primarily cedar trees) has resulted in Table Rock Lake's bass fishery once listed as "tough" becoming one of the top 10 bass lakes in the USA. This has increased the number of tournaments held per year and improved the economic return from the lake to local communities.

Costs

The total cost of the Table Rock Lake project between 2007 and 2013 was $4 million. These costs were met by funding from multiple project partners and funding sources.

The costs and benefits of utilizing various different habitat structure types should always be considered when planning habitat projects. The project is somewhat unique in that the construction and installation costs of each habitat structure type used were calculated (Allen et al. 2014). This information enables cost : benefit to be estimated and is important if the work is to be repeated in more than one site or area. One area the project did not assess was structure durability. Some habitat types may be very cheap to install, but may require regular replenishment. Conversely some habitats, such as rock, have a high initial installation cost but are essentially permanent structure requiring no maintenance or replenishment. This information would be important in calculating the longer-term cost : benefits of each habitat type and developing the most cost effective enhancement strategy. A new project is planned to commence shortly that will investigate the persistence of different habitat structure types and degradation timeframes. The project will be undertaken in three lakes and also look at different design and depth preferences of fish.

The following data is adapted from Allen *et al* (2014) for the estimated installation cost of each habitat type installed in Table Rock Lake. The cost estimates given were for structures of equivalent total size and the assumption that there were no purchase costs for the habitat material.

- Pine structures were the least expensive to install ($162.50 per structure), but surveys indicated minimal use by key fish species.
- Hardwood and cedar brush structures ($266.00 per structure) were more expensive to install than pine structures due to their size. The hardwood and cedar trees were much larger and often required the use of large equipment to place them on the habitat barge. Hardwood or cedar habitat structures attracted both black bass and crappie and were some of the more cost effective habitat structures installed.
- The final size of installed pine, cedar and hardwood structures were generally the same, but the pine structures were composed of more trees.
- Rocks and stumps also attracted fish but were more costly to install (Rock $1677.50 per structure and stumps $1342.00 per structure). The area that can be covered by placing rock or stump structures should be considered when determining the proper materials and techniques to be used. Rock is also permanent, and would provide long lasting benefits to fish when installed in these areas.

Governance

The Table Rock Lake project was the result of many companies, agencies, organisations and individuals working together to produce the best results for improving fish habitat and water quality in reservoirs. The Missouri Department of Conservation was one of the lead organisations and worked in cooperation with Bass Pro Shops, the National Fish and Wildlife Foundation, Arkansas Game and Fish Commission, the United States Army Corps of Engineers, Table Rock Lake Water Quality Inc. and many other partners. Working with as many partners as possible to complete objectives was vital to the success of such a large scale project. Most agencies had only enough resources to contribute a single staff member to the project. This can be problematic as one person typically may not be able to complete all aspects of a project of this magnitude.

Installation of habitat structures in the lakes was the primary task of the lead biologist on the project and required the most attention and effort. Expertise on habitat placement and improving water quality was gained many ways, but one of the most helpful methods was meeting with anglers, focus groups, and stakeholders. Many meetings were held to raise awareness of the project, promote project publicity, and obtain input from the public on how work within the reservoir should be completed. Many of the habitat structure installation projects on Table Rock Lake were completed using information provided to biologists by angling guides and avid anglers in the specific areas where projects were taking place (Allen *et al.* 2014).

As with any project or management technique, funding was a primary concern. For the Table Rock Lake habitat improvement project, Bass Pro Shops committed $300,000 per year which was matched two-to-one by National Fish and Wildlife Foundation and its partners including the U.S. Fish and

Wildlife Service, the Missouri Department of Conservation and Arkansas Game and Fish Commission. These contributions initially occurred for 6 years. Individual partners have continued to contribute resources to keep the project going following the initial arrangement.

Relevance to Australia

The Table Rock Lake National Fish Habitat Initiative project is an outstanding example of what can be achieved by a comprehensive habitat enhancement program in a reservoir and provides an excellent blueprint for a similar large-scale project in Australia. The project incorporated extensive community, end user and stakeholder consultation and dialogue, comprehensive planning, adaptive management and a scientific approach to determine best practice. Following a similar process in a large, degraded or degrading Australian reservoir would provide much of the data and information necessary to assess the suitability and effectiveness of habitat enhancement projects for Australian freshwater species.

Lake Havasu, Arizona

The Lake Havasu Fisheries Improvement Program was formed in 1992 to improve the fisheries in the lake which were declining. The program's timeframe was initially for a 10 year period; however the success achieved resulted in some activities still continuing today. A new memorandum of understanding was signed in 2002, covering future maintenance and monitoring activities. The program was one of the first large-scale and most comprehensive attempts to rehabilitate and improve a reservoir fishery through habitat enhancement anywhere in the world. It has been extremely well planned and managed and the program has produced exceptional results for the lake's fishery. As one of the largest and most successful fish habitat improvement projects ever undertaken in the USA, it is an excellent example of what can be accomplished when government natural resource agencies, anglers and interested members of the public and private sector work together on behalf of the future of recreational angling. The program contained a strong scientific focus and included evaluation of the effectiveness and duration of each of the structure types installed. The Lake Havasu Fisheries Improvement Program is also one of the only projects of its type to provide a detailed socio-economic impact analysis on the work done. This analysis was one of the inspirations for me to become involved in this field of work and to strive for similar benefits to occur in Australia. The following case study was primarily prepared from interviews with Doug Adams (Project leader - Bureau of Land Management), key stakeholders and two excellent peer-reviewed publications on the Lake Havasu Fisheries Improvement Program by Jacobson and Koch (2008) and Anderson (2001).

The Technical Advisory Committee for the Lake Havasu Fisheries Improvement Program

Description

Lake Havasu is located on the Colorado River along the Arizona–California border. The reservoir was formed in 1938 by the construction of Parker Dam for the primary purpose of providing water storage and power generation with secondary functions of flood control and recreation. The surface area of the lake encompasses 10,125 hectares with a shoreline length of 720 km. The lake has a maximum depth of 27 metres and an average of 11 metres. The water level in the lake is very stable due to several dams further upstream on the Colorado River and typically fluctuates less than 1 metre annually. The water in the lake is also very clear due to a generally rocky, gravelly substrate and sediment deposition occurring in the dams upstream. Strong inflows down the Colorado River into the lake results in minimal issues with thermoclines and a water turnover rate of just 17 days for the lake.

Lake Havasu provides a major recreational area in an arid region where large natural bodies of water were non-existent. It is well known for its recreational fishing and boating, which bring in around 750,000 visitors a year. The lake now ranks among the best fishing in Arizona and is possibly one of the best fishing lakes in the Southwest USA. Lake Havasu is best known for its striped bass, largemouth bass and smallmouth bass fishing. It also has good fishing for channel catfish, flathead catfish, and sunfish, including some very large redear sunfish. There are also abundant introduced common carp and limited numbers of crappie. The fishery relies upon natural recruitment for most species, but some catfish are still stocked.

Issues

Prior to establishment of dams, the Colorado River was renowned for its thick red sediment load and several native species of riverine fishes. The original channel of the Colorado River was covered by a large number of cottonwood trees. Construction of Parker Dam flooded these trees providing initial habitat for the development of a bass and crappie fishery (Anderson 2000). Striped bass were introduced which fed on the smaller bass and crappie as well as native fish in the area. However, the success of the fishery depended on habitat suitable for the production of food for forage fish and also habitat suitable for spawning.

The flooding of trees, bushes, rocks and soil initially provided plentiful habitat for the forage fish, crayfish and new young fish to develop. This provided a strong food chain for the development of good largemouth bass, crappie and striped bass populations. Over time the habitat disintegrated and became barren for fish. In addition, because the lake was reasonably shallow, the cottonwood trees were a hazard to boating, so were removed from the lake in the late 1960s. These trees had been naturally disintegrating since flooding, but their removal further decreased the amount of habitat available for fish.

The decline in habitat and reduction in nutrient input into Lake Havasu resulted in a decline in the sports fish and native fish populations. The effects of habitat loss combined with increased angling pressure prompted the various agencies with management responsibilities for Lake Havasu to find solutions to fix the declining fishery. This led to the Lake Havasu Fisheries Improvement Program eventually becoming established.

"In the late 1980's, fishing was only getting worse, native fish were almost extinct and anglers without boats could not access the shoreline to be rejuvenated with a day of fishing" *Mid Program Review (1998) cited in Anderson (2000).*

Fisheries objectives

- To reverse the declining Lake Havasu sport fishery that was the result of degraded aquatic habitat and increased angling pressure
- To improve shoreline access for non-boating anglers, including anglers with physical disabilities

Actions

Discussion among several state, federal and private groups regarding the poor sport fishery at Havasu resulted in the formation of the Lake Havasu Fisheries Improvement Program in 1992. The principal approach used to re-establish the lake's fisheries centred on improving habitat in the lake through the deployment of artificial habitat structures. The initial phase of the program involved establishing program administration, completing an environmental assessment and developing a management plan.

Three staging areas, referred to as work camps, were established to construct and deploy the habitat structures. The first work camp was developed on the south end of the reservoir at the Havasu Springs Resort. This work camp was responsible for installing fish habitat in the lower reservoir. After that work was completed, the second work camp was established on the upper end of the reservoir at Campbell Cove. The third staging site was located at Partners Point where fish habitat was constructed for the central section of the reservoir. This site is still used for the construction of habitat structures that continue to be deployed. The work camps serve as a great field station for the storage of vessels, construction of habitat, general storage, shelter for workers and launching and loading the barges.

A total of 1,410 hectares of habitat was installed in the first 10 years of the Lake Havasu Fisheries Improvement Program. Initial surveys were conducted with sonar to identify areas where habitat was needed and the conditions were suitable. A comprehensive map of the artificial habitat structures for each cove was developed prior to placement. Factors such as water depth, navigation, proximity to shoreline facilities, natural cover, topography, and sediment inflow were taken into consideration when deciding on the design and placement of the artificial habitat structures (Jacobson & Koch 2008).

A variety of habitat structure designs were developed and the designs underwent continual evolution based on feedback from the construction and deployment teams and observations of fish usage. All structures were built by volunteers, so designs needed to be easy to construct, readily learned and repeatable. Taller habitat structures were constructed for use in deeper water situations and brush was added inside these structures after observations from divers indicated that more fish occupied structures containing both materials. Space between structures was adjusted to less than 1.8 metres to improve performance of each structure by increasing the edge effect for smaller fish. A variety of structures have been deployed to provide a range of benefits to fish. Large structures were deployed to aggregate larger adult fish whilst smaller structures with finer structures and interstitial spaces (like brush) were installed to provide habitat for juvenile and forage species. The range of structure types installed included snow fence cylinders, snow fence cubes, pipe bundles, fishing forests using the "Fish-N-Tree™" units (commercial product made by Berkley) and brush bundles. Trees are rare in the area due to the desert environment, so brush bundles are typically used as a source of natural material. In the first ten years of the Lake Havasu Fisheries Improvement Program more than forty–two sites (coves and associated points) had habitat improvements, totalling approximately 1410 hectares and involving around 135,000 pieces of habitat structure. In terms of the actual habitat, 67,482 bass shelters, 54,724 catfish houses, 3,484 bass ambushing cover structures, 1,050 tyre towers and 11,800 brush bundles were placed in the lake.


Brush piles loaded on the barge ready to be deployed by volunteer. PVC and snow-fence structure starting to break down. Boat anchors can have a large impact on these structures.

Additional habitat structures continue to be introduced since the end of the initial 10 year program and currently brush bundles are the preferred habitat to install. The brush is donated from local residents, landscape gardeners and maintenance staff who deliver the materials to the Partners Point work camp. The volunteers then assemble suitably sized piles of the brush, tie it together with manila twine and attach sand bags to anchor the structures down. Each month between 80-120 brush piles are installed by the volunteers. In the past 10 years this would equate to approximately 10,000 additional structures deployed in the lake. Brush piles tended to last less than 7 years before deteriorating, whilst piles made from palm fronds typically lasted less than 3 years before needing replenishment. To overcome this, brush piles in each cove are supplemented by 10% each year to counter deterioration of the materials.

More than 90% of the Lake Havasu's shoreline consisted of desert terrain with no angling access. To improve angler access 6 fishing piers and 80 boat-only accessible campsites have been constructed specifically for anglers. Brush piles were densely placed around these sites, just out of casting distance, to attract fish to the area. Additional habitat structures have been placed beneath the floating piers to further attract fish.


Brush and vegetation trimmings piled up and ready to be tied into brush piles and the finished result with sandbag anchors loaded on the barge

A commercially available map has been produced to help anglers locate habitat in the main deployment sites. The paper map must be purchased and currently there are no free ways for locals or tourists to otherwise identify these locations. Some of the project parties would prefer to see the level of extension improved, especially to provide tourists better information on where to fish.

The condition of the structures is monitored every year by a specialist dive team from the Bureau of Reclamation. The divers visit a rotating selection of coves each year and visually assess the condition of the installed habitat and categorically rate the habitat for overall structure condition, algal accumulation, sediment accumulation and coverage of the invasive quagga mussel. Visual assessment of the fish abundance on each structure was historically recorded; however the results were too highly influenced by water clarity, so that the process was discontinued.

The fish community around 3 year old brush piles. Note the diversity in fish sizes and species.

Annual electrofishing surveys are conducted by state fisheries agencies throughout the lake to assess changes in the abundance and size distribution of key fish species. The electrofishing efforts historically were not always standardised, but a consistent practice has been implemented for the past few years. There are 400 electrofishing survey points across the lake and each year 36 of these are randomly selected for survey. The shoreline at each site is electrofished for 15 minutes and the fish captured identified, counted and measured. Trammel net surveys were also undertaken at many sites, but the results were found to be to variable for statistical comparison. Creel surveys are used to assess the fish population, angler catch rates and angler perceptions. Anglers United currently have volunteers conducting the creel surveys and plan to interview 1100 people over a period of 13 months.

Outcomes

It has been difficult to directly discern the impacts of habitat enhancement on the Lake Havasu's fish population because it appears there are many confounding variables. Biological information on the catch rates and size distributions collected during fisheries surveys generally remained consistent for most species. The data proved to be highly variable and inconclusive and was likely confounded by environmental variables. Despite this, Jacobson (2001) concluded that since the start of the fisheries improvement program:

- The size of channel catfish appeared to increase
- There appeared to be a slight increase in the size of largemouth bass
- The proportional stock densities for largemouth bass improved
- The percentage of stock size bass over 15 inches increased
- The black crappie population at the lower end of Lake Havasu increased drastically and the flathead catfish populations appear to also increase

Despite the failure of evaluation efforts to detect strong changes in fish community dynamics, the benefits from the habitat improvement program in Lake Havasu have been outstanding for anglers. Even though more people were fishing more regularly, anglers caught more and sometimes larger fish. More specifically:

- The number of people fishing the lake doubled
- Angling pressure quadrupled (43,000 to 175,000 angler use days per year)
- 97% of those anglers noticed an improvement in the quality of the fishery.
- Angler success rate at catching a fish has tripled
- Angler's catch rates have more than tripled
- Anglers were keeping three times as many fish
- The size of largemouth bass being caught by fishermen has not decreased as a result of increased harvest
- The size of channel catfish being caught by fishermen increased
- The number of angling tournaments increased significantly; 40 national and regional fishing tournaments returned Lake Havasu to their circuit schedule after more than a decade of absence
- Tournament data show that in addition to these improvements, a substantial and growing population of small mouth bass has developed at Lake Havasu

The angling access areas and piers that were installed to improve shore-based angling opportunities were well patronised and anglers using these structures consistently caught fish. These facilities received more than 80,000 angler use days per year. The piers were also regularly used for sightseeing, bird watching, family outings and other activities, and provided the opportunity to experience the Lake Havasu area. The fishing at the new piers has become so good that even tournament anglers are fishing from them during tournaments. These are the typically the most dedicated anglers on the lake, being primarily focused on productivity. Pier use was highest amongst Lake Havasu residents who also valued the areas for the amenity values.

Fishing piers have been installed to improve shoreline access for anglers. These areas were also loaded with habitat to attract fish within casting range.

Although many projects have attempted to improve sport fisheries through use of habitat enhancement programs, few have been able to show benefits to the wider community. The resulting increase in fishing activity, and associated fishing related expenditures in the local area, have produced significant, long term socioeconomic benefits to the local area, including increases in employment, income and tax revenues. The economic impact assessment by Anderson (2001) estimated that the improved fishery in Lake Havasu was providing an annual economic benefit within the local area of $51.5 million and 1289 jobs. Importantly, $33.8 million of this was generated by non-residents who were bringing their tourism dollars into the region. All figures are in US dollars. These benefits are expected to last into the foreseeable future with relatively low program and structure maintenance costs.

Anderson (2001) calculated non-resident fishing expenditures in the Lake Havasu generate the following economic benefits within the local area:

- Value added of over $18 million per year
- Labor income of over $11 million per year
- Employee income of about $10 million per year
- Proprietors income of about $1.32 million per year
- Property income of about $4.5 million per year
- Indirect business taxes of about $2.4 million per year
- 650 jobs per year
- Total output of about $33.8 million USD per year (equivalent to $51.2 million AUD in 2016)

In addition, resident anglers' expenditures in the local area generates an additional $17.7 million USD (or $26.8 million AUD) in value, 639 jobs, and $2.6 million in state and local tax revenues.

Another economic point worth considering is the value of tournament angling. The connection between fishery quality and tournament interest has been identified in the conclusion section of a study on attitudes and impacts of tournament participants in Virginia Beach, Virginia. The study completed by Thailing (2001), concluded:

"If fish stocks continue to decrease, angler satisfaction with the tournament fishing can be expected to decrease as well. When this occurs, anglers will be attracted to tournament events elsewhere, resulting in economic impact losses to the local community. The take home message here is that the current status of fish stocks is connected to fishing quality, which is linked to angler satisfaction, which is linked to their willingness to participate in local fishing tournaments on the regular basis. Fishing quality now and in the future is an important consideration for successful fishing tournaments".

This sentiment is pertinent to Lake Havasu which has seen the return of more than 40 tournaments and their economic benefits following the success of the Lake Havasu Fisheries Improvement Program.

Costs

The initial cost estimate for meeting the objectives of the Lake Havasu Fisheries Improvement Program for the first 10 years totalled roughly $28.5 million. The Bureau of Land Management arranged for federal funding to pay for half of the annual costs; the other partners agreed to contribute the remainder, contingent upon budgetary availability. The final cost of the program was less than half of the original $28.5 million estimate. According to Jacobson and Koch (2008) non-federal sources provided more than $7 million to the program and volunteer labour contributed more than 170,000 hours of service in the construction and placement of artificial structure valued at more than $2 million.

Governance

The governance structure was well described by Jacobson and Koch (2008) and the following is adapted from their report.

The partnership program was initiated through development of a cooperative plan that defined social, environmental, and economic needs for management of Lake Havasu. A Memorandum of Understanding (MOU) committed the seven parties involved in the welfare of Lake Havasu to the program vision. The MOU fostered cooperation and coordination and described procedures to be used by the partners in managing the program. The MOU also facilitated exchange of information as well as sharing of personnel to accomplish the monumental tasks that were ahead. The partnership was based on the mutually benefiting aspects of the program and depended on voluntary contributions to accomplish the program objectives. Each partner had strengths in various areas that were required to achieve the desired results. A full-time coordinator was hired to meet the need for continued communication among various levels of the partners, supporters, local communities, counties, and volunteers.

The structure of the partnership established by the MOU consisted of an Executive Committee that made key program decisions and a Technical Committee that assured quality control and developed management proposals. The Executive Committee consisted of agency directors or their representatives and their function was to approve the initiation of new projects, review and approve products used during the restoration process, and provide information to be used by legislators or the Congressional delegation to obtain funding for the program. A simple majority of the partners constituted a quorum and was sufficient to conduct business.

The Technical Committee served at the direction of the Executive Committee. The Executive Committee members appointed experts within their organisations to provide recommendations and options for implementation of the program objectives. The Technical Committee chair appointed various task forces to carry out specific tasks assigned by the partners, with Executive Committee approval. The composition of each task force varied depending on the cooperative project being pursued. Once the project was completed and approved, the task force was dissolved.

Each partner was encouraged to plan for and request separate annual appropriations for cooperative actions scheduled during a given fiscal year. Interagency and cooperative agreements, cost sharing, and pooling of expertise and resources allowed the program to run efficiently. Supplemental agreements were often created for special projects to describe co-operator responsibilities in terms of deadlines, contributions, operations, and long-term maintenance.

The partner organisations involved in the Lake Havasu MOU and their role in the project

Organisation	**Organisation Type**	**Role/Contribution**
U.S. Bureau of Land Management	Federal government	Lead agency who oversee data management and partner coordination, monitor habitat for fish and wildlife, and provide recreation maintenance
U.S. Bureau of Reclamation	Federal government	Provide expertise in water conservation, engineering, sensitive species, and public access.
U.S. Fish and Wildlife Service	Federal government	Provide expertise in sensitive species, Indian fish trust and wildlife refuge management.
Arizona Game and Fish Department	State government	Provide expertise in management of the fisheries resources, sustaining resource viability, and public safety
California Department of Fish and Game	State government	Provide expertise in management of the fisheries resources and sustaining resource viability.
Metropolitan Water District of Southern California	Waterway manager	Provide expertise in water quality assurance and sensitive species conservation.
Anglers United	Volunteer angling group	Provide expertise in raising private funds and support for the volunteer efforts

Relevance to Australia

The Lake Havasu Fisheries Improvement Program demonstrated that reservoir fisheries can be improved significantly at a large-scale and in a cost-effective way if stakeholders are willing to work together and commit to long term goals. The project was unique in that angler catch and satisfaction in the lake improved through the installation of a range of habitat structures, despite limited biological evidence that such improvements were occurring. This was more likely due to the technical difficulties in monitoring fish populations in a reservoir of such large size, but demonstrates the importance of including angling metrics in the evaluation process. Additionally, the project is one of only a few to have included comprehensive cost : benefit analysis. It demonstrated clearly that improving reservoir or impoundment fisheries can produce significant and lasting economic benefits to local communities. It is highly likely that similar benefits could be accrued from similar projects in Australian impoundments. The restoration process in Lake Havasu was driven by a team of technical experts, but almost all of the labour came from dedicated and engaged volunteers. In Australia, and in particular Queensland, the local angling and stocking groups are already heavily engaged in reservoir fisheries management and could potentially provide a similar labour source. Following project establishment, the ongoing cost of replenishing existing brush structures and deploying habitat at new sites was comparatively very low and potentially within the budgets of many groups. Such an approach would be viable in Australia, particularly if the burden is shared.

Lake Cottonmill, Nebraska

The restoration of the fishery in Lake Cottonmill provides an excellent example of how habitat enhancement can effectively resurrect a highly degraded fishery in a small reservoir and provide significant benefits to the local area. It is one of the few reservoir restoration projects to estimate the economic benefits of reservoir fishery restoration. The majority of the information contained in this case study came from the project summary by Spirk *et al.* (2008).

Description

Cottonmill Lake in Buffalo, Nebraska is a small 17.4 hectare reservoir originally created 1886 as a storage reservoir to generate power for the old Cottonmill factory in Kearney. The lake experienced heavy sedimentation which reduced the mean lake depth from 3.6 m to as little as 0.7 m in 1994.

Prior to the lake restoration the fishery was dominated by “coarse-fish” with angler catches of more desirable sports and pan fish low. Since the restoration, Cottonmill Lake now boasts healthy populations of largemouth bass, smallmouth bass, spotted bass, bluegill sunfish, crappie and channel catfish.

Issues

Lake Cottonmill suffered extensively from the impacts of eutrophication and sedimentation. These factors decreased water volume, smothered spawning sites, reduced aquatic vegetation and increased the prevalence of harmful algal blooms. The fishery in the degraded lake became dominated by coarse-species such as carp leading to poor catches for anglers and ultimately poor angler visitation rates.

Fisheries objective

- To restore viable sports and pan fish fisheries in the lake and increase angler catches and visitation rates.

Actions

The lake rehabilitation project at Lake Cottonmill commenced in 1997. Rehabilitation activities included draining the lake, the removal of approximately 84,995 m^3 of accumulated sediment, fish population renovation, and creation of four breakwater jetties, two islands, and multiple underwater structures including: rock piles, wooden cribs, and cedar trees to benefit bass species. The lake was stocked several times with bluegill, largemouth bass and channel catfish following re-flooding.

Outcomes

The rehabilitation project was very successful at improving the fishery and attracting increased angler effort. Standardised pre and post-restoration surveys of the fish community using nets and electrofishing revealed significant increases in the relative abundance of largemouth bass and bluegill sunfish. A small increase in the abundance and mean size of channel catfish was observed as well. Water quality and the coverage of aquatic vegetation also improved significantly.

Creel surveys revealed a substantial increase in angling effort and catch rates. Angler visitation rates increased from 394 to 5,561 angler days between 1993 and 2006 and the amount of time spent angling increased from 503 to 11,122 hours. Along with increased fishing pressure, the total angler catch tripled between 1993 and 2006 (0.5 fish/hour to 1.5 fish/hour). Anglers caught significantly more bluegill sunfish, largemouth bass and channel catfish following the restoration.

Costs

The total cost of the restoration project was estimated to be approximately $1.5 million and was contributed to by Nebraska Game and Parks Commission, Nebraska Environmental Trust Fund, the Nebraska Department of Environmental Quality and the Central Platte Natural Resource District. Restoration of the lake resulted in a significant increase in angler expenditure in the local area. Based on the average daily expenditure of anglers in Nebraska, the estimated angler expenditure in May/June at Lake Cottonmill increased fourteen-fold, from $26,004 in 1993 up to $367,026 in 2006. The additional estimated expenditures by anglers at the lake should surpass the lake restoration costs in only a few years and deliver long-term economic benefits to the local area.

Governance

The Lake Cottonmill restoration project was a joint effort between Nebraska Game and Parks Commission, Nebraska Environmental Trust Fund, the Nebraska Department of Environmental Quality and the Central Platte Natural Resource District.

Relevance to Australia

This example of lake restoration through environmental re-engineering demonstrates that significant benefits can be accrued for the rehabilitation of even small reservoirs with low angler visitation. Once word get around that a lake is fishing well more anglers will come and the effects will snowball. In Australia there are many smaller reservoirs around the outskirts of major cities that could experience similar economic and social benefits from a comparable restoration program. The initial cost of the Lake Cottonmill project was around $1.5 million, which to some may sound large, but the economic benefits to the local area could cover this in less than 5 years. If the cost is shared amongst stakeholders then individual investment for organisations would be at a level that could be achieved.

Lake Conroe, Texas

The restoration of the fisheries in Lake Conroe provides an excellent example of the benefits of habitat enhancement in a reservoir with a large urban population (200,000 residents) and high angling pressure. The extensive urban development around the lower end of the reservoir limits the types and locations where habitat enhancement can be undertaken and creates a broad spectrum of stakeholders. The following case study was primarily prepared from interviews with Mark Webb and Alice Best from Texas Parks and Wildlife Department, and the Lake Conroe Management Committee.

Description

Lake Conroe is situated in Texas on the west fork of the San Jacinto River. The lake was built in 1973 as the reserve water supply for the city of Houston and covers an area of 8,500 hectares. The average depth in the lake is 6.2 meters with a maximum of 24 meters. The water quality in the lake is typically high. Lake Conroe is dominated by open water in the lower two-thirds of the reservoir, with some standing timber still present along the river channel in the upper reaches. Bulkheads with boat docks dominate the shore in the lower reservoir, whilst the upper reservoir (the portion lying within the Sam Houston National Forest) is primarily featureless shoreline.

Largemouth bass and channel catfish are the primary fisheries in the lake, with other angling targets including white and hybrid striped bass, crappie and large bluegill. Black and white crappie fisheries have made a comeback in the lake since the stockings of advanced juvenile fish.

Issues

The primary issue at Lake Conroe was the need to enhance littoral habitat including the native aquatic plant community while controlling invasive exotic aquatic vegetation. The degraded littoral habitat was detrimentally impacting fisheries in the lake, particularly for largemouth bass which experienced poor recruitment when native aquatic vegetation was scarce.

Lake Conroe has been in a state of flux since its impoundment in the late 1970’s with an early infestation of hydrilla followed by total removal of the aquatic plant community by 270,000 diploid grass carp stocked in the early 1980’s. Native vegetation restoration was begun in 1995, but increased nutrient loading caused by rampant urbanization along with attrition of the grass carp population led to a re-infestation of the reservoir by hydrilla and water hyacinth. In addition, the exotic aquatic fern, giant salvinia, was discovered in Lake Conroe in 2000.

Fisheries objectives

- To enhance recruitment and growth of native fish species by establishing native vegetation
- To create artificial reefs to aggregate fish to increase catch rates and angler satisfaction

Actions

The Lake Conroe Habitat Improvement Project was commenced in 2005 to develop habitat enhancements for fisheries and ecosystem improvement at Lake Conroe. As part of this project the Lake Conroe Habitat Management Plan was created in 2006 to manage the exotic vegetation and enhance the native aquatic plant community. Implementation of the plan successfully controlled the exotic vegetation, but the grass carp used as part of the integrated pest management strategy also had severe impacts on the native vegetation, with flow-on effects on the lake's sports fisheries. The second phase of the project focussed on re-establishing grass carp tolerant native aquatic vegetation to increase littoral fish and wildlife habitat and installation of four one-acre structural habitat areas to create fishing hot spots in the lower reservoir to increase fish production and angling success.

The native revegetation was established in the upper reservoir by installing numerous 2.4 x 4.8 meter enclosures planted with a variety of native aquatic vegetation. The exclusion fences kept grass carp and turtles from feeding on the re-establishing vegetation, but hydrilla has dominated in some plots without this grazing pressure. Thirty to thirty-six vegetation enclosures could be established over a period of two days.

For a short clip on the re-vegetation program visit https://vimeo.com/49683777

Exclosures were important when initially re-establishing aquatic vegetation in areas with grazing species such as turtles and grass carp.

The location of the structural habitat areas were selected by using topographic maps to identify areas that were between 5.1-6.0 metres at normal water level and which would remain sufficiently submerged during drought conditions to avoid becoming a navigational hazard. The selected sites also were required to have existing fish attracting structure that could be supplemented with the artificial habitat. Initially the habitat enhancement areas were located in the lower, more urbanised section of the reservoir. The structures used were standard spiders with additional bamboo stems. These were deployed from boats in a radial pattern around a centre point, consisting of 12 outward lines each made up of 12-13 spiders.

Modified spider blocks ready for deployment in Lake Conroe by the Seven Coves Bass Club

Presentations on the project have been given to numerous civic and conservation organisations as well as at scientific meetings. Using the example of the Lake Conroe Project, Texas Parks and Wildlife Department is working with schools and conservation organisations to develop similar projects at Lake Houston, Lake Livingston, Lake Waco, Fort Boggy State Park Lake, and Lake Raven in Huntsville State Park. The San Jacinto River Authority uses the habitat conservation project as a key element in the school and youth outreach program. Students from area schools also volunteer for in-lake habitat improvement including vegetation planting and structural habitat. Recently a Conroe High School student worked with project partners to accomplish structural habitat placement as part of an Eagle Scout Project. Extensive coverage has occurred in television, print, radio and online media formats.

Outcomes

The Habitat Enhancements for Fisheries and Ecosystem Improvement at Lake Conroe, Texas project was designed to provide self-sustaining and expanding habitat improvements that will continue to improve the Lake Conroe ecosystem for fish and other wildlife and human uses. The native vegetation component has and will continue to mitigate the increasing effects of urbanization (nutrient enrichment, sedimentation, etc.) in the watershed with little or no additional expense to residents and other users. A number of the native aquatic vegetation species used in the enclosures have established well and now spread beyond the enclosures. The process is working but has taken a long time. It took several years before the native vegetation became well established in the enclosures and started spreading beyond the fence. Once a critical density was reached, the impact of grazers on the vegetation population became less significant. Unfortunately a severe drought in 2011 resulted in extremely low water levels which detrimentally impacted the density and distribution of some native aquatic plants.

The structural habitat areas created in the lower reservoir have been extensively used by anglers. Creel surveys have shown there has been a tripling in the number of hours for bass tournaments between 2008-09 and 2012-13 on the lake (Webb *et al.* 2014). Despite this increase in effort, the total largemouth bass catch harvest weight by tournament anglers has increased more than eight-fold. The average number of fish caught has varied little; suggesting tournament anglers are now catching larger fish for the same effort. This is supported by the electrofishing data (Webb *et al.* 2014) where the mean size of fish has increased. However, the electrofishing surveys identified only a small increase in the catch rate of juvenile largemouth bass, suggesting that there has been no large improvement in natural recruitment following the re-establishment of native aquatic vegetation beds. The harvest and size of channel catfish by recreational anglers doubled from 2008-09 to 2012-13 with anglers taking more and larger fish.

The direct link between the catch rate or size increases in key sports fish and the habitat enhancement that has been undertaken remains unclear. However, electrofishing surveys have identified increases in the abundance of prey species between 2008-09 and 2013-14 (Webb *et al.* 2014). An increased abundance of food may explain the greater sizes or abundance observed in the predatory fish species and could be a result of the increased amount of native aquatic vegetation that has been re-established.

The surveyed anglers were all highly supportive of the project and much of the volunteer labour in the project has come from angling clubs. One angler suggested to me that anglers now have a lot more optimism about catching more and better fish each trip. Anecdotally this suggests that angler satisfaction is increasing following the habitat enhancement efforts.

Costs

The total cost over the first 9 years of the Lake Conroe Habitat Improvement Project was approximately $1,000,000. This amount comprised:

Native aquatic vegetation establishment nursery and field plantings –$300,000.
Exotic aquatic vegetation control - $600,000.
Structural fish habitat –$60,000.
Outreach, education, and publications –$40,000.

The majority of the funding has been spent on the control of the exotic vegetation and the establishment costs for the nursery. These values do not include costing the volunteer labour which has been significant and without which the project could not have occurred. For comparison, in 2012-13 the total angling expenditure on Lake Conroe was estimated at $1,244,774 and the total angling effort was 184,408 hours (Webb *et al.* 2014). There is insufficient data available to ascertain the total economic cost : benefit for the project so far.

Governance

The project was directed by a steering committee comprising key representatives of all the major stakeholder groups. A broad range of stakeholders have been involved in the project and the table below indicates the organisations and their role in the project.

The organisations involved in the Lake Conroe steering committee and their role in the project

Organisation	Organisation Type	Role/Contribution
Seven Coves Bass Club	Fishing club and conservation organisation	Core partner providing organisation, labour, funding, and outreach
Reservoir Fisheries Habitat Partnership, Friends of Reservoirs	Conservation organisation	Core partner providing organisation, labour, funding, and outreach
BASS, Texas BASS Federation	Fishing club and conservation organisation	Core partner providing organisation, labour, funding, and outreach
Dockline Magazine	Media	Core partner provided education and outreach publications
San Jacinto River Authority	Lake Conroe controlling authority	Core partner providing organisation, labour, funding, and outreach
U.S. Army Corps of Engineers	Federal agency	Core partner providing organisation, technical support, labour
Texas Parks and Wildlife	State agency	Core partner providing organisation, labour, funding, and outreach.
Texas Black Bass Unlimited	Fishing club and conservation organisation	Partner providing organisation, labour, funding, and outreach
Texas Association of Bass Clubs	Fishing club and conservation organisation	Partner providing organisation, labour, funding, and outreach
Lake Conroe Association	Home owners association	Provided funding for purchase of triploid grass carp for exotic vegetation control
Toyota Texas Bass Classic	Outreach event organisation	Provided funding and outreach
Toyota	Corporate sponsor	Provided funding and outreach
Bass Pro Shops	Corporate sponsor	Provided funding and outreach
U.S. Forest Service – Sam Houston National Forest	Federal agency	Partner providing funding and technical support
Texas A&M University	University	Partner providing labour and technical support
University of North Texas	University	Partner providing labour and technical support
Entergy	Power production corporation operating in the Lake Conroe	Partner providing labour and technical support

Relevance to Australia

In Australia, extensive urban development around reservoirs has traditionally been relatively uncommon, but is increasing with the inclusion of lakes in many new large housing developments. As Australia's population grows, there will be more demand for land near inland waterbodies and the impacts of urbanisation will become more evident around reservoirs. The management actions to improve the fishery at Lake Conroe demonstrate that recreational reservoir fisheries can be improved through careful planning and stakeholder involvement, despite pressure from high urban development and substantial angler usage. A key observation from this project that can be directly applied to Australia was the selection of different remedial activities for different parts of the reservoir based on land use. In more developed areas, re-establishing native aquatic vegetation was unlikely to be successful due to the desires of waterfront land-owners and extensive bulkheads. In these areas it was however acceptable to install habitat structures in deeper water. The vegetation re-establishment was only conducted away from residential houses in the upper reservoir. However, the local residents still gained a significant benefit from the work that was done as the fishery improved.

Lake Athens, Texas

The Lake Athens fishery is a somewhat unique example of the benefit to anglers from restoring aquatic vegetation. The restoration of the aquatic plant community and the introduction of other habitat enhancements have completely rejuvenated this reservoir fishery. The following case study was primarily prepared from interviews with Richard Ott and Kevin Storey from Texas Parks and Wildlife Department.

Description

Lake Athens is a 729 hectare eutrophic reservoir on Flat Creek, a tributary of the Neches River, Texas. The lake was built in 1962 for town water supply for Athens and recreation. The maximum depth in the lake is 16 m and water levels rarely fluctuate more than 1.2 metres. The shoreline is primarily featureless or a combination of featureless/bulkhead, rip-rap and boat docks. There is also a small amount of inundated standing timber in the middle of the lake.

Lake Athens is primarily known as a largemouth bass fishery, although there are also fisheries for white bass, channel catfish and black crappie.

Issues

Lake Athens has historically contained a stable, diverse aquatic macrophyte community primarily composed of native species. There was a marked decline in native aquatic vegetation. The native aquatic vegetation is vitally important for spawning and recruitment for the lake's sports fish. The exotic weeds hydrilla, water hyacinth, and alligatorweed were also identified within the lake and had the potential to interfere with boat and angling access, and fisheries production should they become abundant. Lake Athens has a history of producing trophy-sized largemouth bass and the lack of habitat or prevalence of exotic species had the potential to lessen the prevalence of these fish and impact the ecosystem. Additionally, structural habitat was scarce in the deeper parts of the lake and may have contributed to poor sunfish and crappie fisheries.

Fisheries objectives

- To improve littoral habitat for largemouth bass to ensure consistent natural recruitment
- To provide habitat to aggregate largemouth bass, sunfish and crappie for anglers.

Actions

A lake re-vegetation program nursery was established at the nearby Texas Parks and Wildlife Department's Texas Freshwater Visitors Centre. A number of beds were set up to propagate native plants for introduction into Texas reservoirs. However, replanting at Lake Athens was not required as re-vegetation occurred naturally in the lake. The overflow water from the display tanks in the visitor centre carried enough native plant material into the lake for the vegetation to re-establish. This established diverse, multi-species vegetation beds around the lake, even in front of the numerous bulkheads surrounding lakeside properties. A drought in 2011 lowered water levels to the point where seeds and propagules had sufficient shallow water and sandy substrate to take and establish. The native aquatic vegetation first returned in the vicinity to the overflow outlet, before spreading around the lake margins. Native vegetation now covers more than 15 % of the total surface area (Norman & Ott 2014) and provides excellent habitat for fish.

Anglers targeting largemouth bass on the margins of the re-established native aquatic vegetation

Quite a few habitat structures were also deployed in the lake to aggregate fish for anglers. The sites where the structures have been added were selected based upon the bottom topography, proximity to deep water, the thermocline and the intended species. Numerous Christmas tree reefs were installed around the dam in 4.5-6.0 metres of water by the Lake Athens Bass Club. These structures consist of sunken bundle of Christmas trees and are primarily fished for black crappie in winter. In summer the thermocline sits between 4.5-6.0 metres so the structures are utilised less by both fish and anglers. It is thought that the Christmas trees attract the crappie into these areas from the vegetation and make them easier to target. The location of these structures has been marked by buoys and the GPS coordinates been made available on the Texas Parks and Wildlife Department website. Additional information on the lake's management and habitat enhancement is available at the adjacent fisheries visitor centre.


Athens Bass Club Christmas tree reefs ready to be deployed into Lake Athens for fish habitat and anglers targeting fish on the installed structures.

Outcomes

As the plant communities have developed in Lake Athens the largemouth bass fishery has become spectacular. Fish size and numbers have both increased as the primary productivity in the lake has increased. The number of anglers using the lake has also increased significantly as well. Anglers target the bass species along the edge of the vegetation and if water levels are high they even fish skipping lures over the top of the plants. The quality littoral habitat present within Lake Athens has also resulted in consistent recruitment of juvenile fish (Norman & Ott 2014). Largemouth bass are now becoming so abundant that special slot limits have been introduced on the lake to encourage angler harvest and ensure trophy sized fish still occur. Excessive bass abundance can lead to a reduction in the mean fish size due to resource limitations. Native floating and submersed species have offered the fish assemblage excellent shallow water habitat and limited the growth and spread of exotic vegetation. The abundance of sunfish has improved greatly and smaller fish are providing a good prey base for most of the game fish species (Norman & Ott 2014). Additionally, larger sunfish have become more prevalent and are likely to soon form a viable harvest fishery.

The impact of the addition of the Christmas tree structures has not been accurately assessed; however total survey catch rates were similar for pre and post structure installation (Norman & Ott 2014). The abundance of predatory largemouth bass and the current small population size may restrict the ability of the black crappie fishery to rapidly improve. Few anglers currently target black crappie in the lake and this may limit increases in the total angler harvest. Electrofishing surveys have identified that larger black crappie have become more prevalent which may lead to an improvement in the fishery in the next few years.

Costs

Habitat enhancement in Lake Athens has only required a small amount of funding so far. There was an initial establishment cost for the aquatic vegetation propagation beds; however after establishment these were not required by the project and have been used for habitat improvements in other lakes. The natural re-establishment of native aquatic vegetation from the visitor centre overflow water has been very effective and at no cost. The cost for the construction and deployment of the Christmas tree bundles is unknown, but likely to have been low. The Christmas trees were all donated by local residents and the only associated costs for their deployment would have been for weights, rope and fuel. The majority of this work has been carried out by volunteers from local angling clubs leading no labour costs being incurred.

Governance

There were no formal governance arrangements in place for the work that has been conducted in Lake Athens so far. Texas Parks and Wildlife Department have been primarily focussing on the aquatic vegetation restoration, whilst angling groups have been mostly focussed on the installation of the structural habitat enhancements.

Relevance to Australia

The Lake Athens case study provides another example where vegetation management combined with the installation of fish habitat structures can lead to significant improvements in reservoir fisheries. The unique scenario of plants re-establishing in the reservoir from the transport of plant propagules in outlets waters from display tanks at the visitor centre saved the project a lot of time and resources and may have broader potential. It is worth investigating whether flowing water through a series of plant propagation beds can effectively lead to wild establishment of the same plant species by a similar process. This strategy would reduce the amount of labour involved in growing and planting aquatic vegetation and could lead to diverse natural, plant communities to support the fishery. If successful this process could be used to help re-establish aquatic habitat in reservoirs following drought or re-engineering.

Many Australian impoundments with stable water levels currently have sufficient amounts of aquatic vegetation to support their fisheries. However, as these impoundments age, habitat degradation is likely to occur. Using overflow water to maintain or improve the aquatic vegetation could help slow or counter the decline and sustain healthy fisheries.

Lake Wichita, Texas

An ambitious large-scale program has recently started to rehabilitate Lake Wichita in Texas. The 114-year-old lake has suffered from decades of siltation, drought, golden algae blooms and urban impacts which have completely collapsed the fishery and heavily degraded the entire ecosystem. The revitalization project will drain and completely re-engineer the lake to re-establish a healthy aquatic ecosystem and create an excellent recreational fishery. The project also includes significant social, recreational and commercial components designed to re-invigorate the local community and economy. This project provides great insight into the planning process for a major reservoir fisheries restoration project and highlights some of the challenges faced.

Description

Lake Wichita is a manmade reservoir on the southern edge of Wichita Falls in north Texas. It is the third oldest reservoir in the State of Texas with construction completed in 1901. Initially the lake had a surface area of 890 hectares, a capacity of 17,270 megalitres, and a catchment area of 350 square kilometres. The reservoir was initially built for town water supply, irrigation and recreation, but as alternate water supplies were developed the lake was re-engineered for flood mitigation in 1995.

This resulted in a lowering of the spillway by 1.43 metres, reducing the surface area of the lake to 495 hectares, mean depth to 1.37 metres and maximum depth to 2.9 metres.

There are currently no viable fisheries left in the lake.

Issues

Having surpassed its expected 100-year life span, in its present state, Lake Wichita is no longer able to provide significant social, economic, ecological, or recreational benefits to the community. In an effort to sustain recreational use, the City of Wichita Falls diverts water from Lake Diversion in an attempt to maintain elevation at or near spillway level. Between 2004 and 2012 several severe golden algal outbreaks killed the majority of the fish in the lake and a major drought in 2012 significantly decreased water levels, driving water temperatures and dissolved oxygen to lethal levels (Lang & Mauk 2012). In 2014, Lake Wichita was nearly completely dry but rebounded in 2015 when torrential rains filled the lake and water again went over the spillway. Despite replenishment of the water level, very few fish remain in the lake and there is no viable fishery.

Lake Wichita with low water levels in 2014. Note the lack of structure and habitat for fish. (image Ben Jacobi)

Fisheries objectives

- To re-establish a world-class recreational sports fishery in Lake Wichita. Texas Parks and Wildlife Department plan to initially create fisheries for Florida largemouth bass, hybrid striped bass, white crappie, bluegill sunfish, redear sunfish, and channel catfish through stocking.
- To re-establish a healthy aquatic ecosystem and habitat to ensure long-term benefits for the revitalised fisheries and aid in natural recruitment.
- Install habitat structures and contour lines to aggregate fish in certain areas and improve angler access to the fisheries resource.

Actions

The Lake Wichita Revitalisation Committee has been established to capture stakeholder information and desires, develop strategies for the revitalisation project and provide direction, leadership and impetus to drive the project forwards. The Committee has developed a Lake Wichita Revitalisation Master Plan with input from all major stakeholders. This is an integrated plan that focusses on revitalization of the environmental, social and economic values of Lake Wichita. The concept is to rebuild the lake specifically for end-users whilst maintaining its value as a water supply. Key to the plan is the re-establishment of the recreational fishery and the ecosystem services necessary to support that fishery.

After more than one hundred years of siltation, habitat degradation, and the lowering of the spillway for flood control, Lake Wichita has been left with a shallow average and maximum depth, little structure, low storage capacity, and little aquatic vegetation. As the lake had nearly dried up completely and has few remnant fish it is planned to drain the lake and conduct a dry excavation of approximately 5.4-million cubic metres of sediment and sculpt the lake bottom in a way that is conducive to good fish and wildlife habitat. It is anticipated that an average of 1.1 metres will be excavated to increase mean depth to 2.4 metres and as deep as 4-5 metres deep in places for structural heterogeneity and drought resistance. The bottom will be sculpted so that the lake will recede quickly to deeper channels during droughts, lowering the surface acreage while retaining a greater storage capacity, ultimately lowering the evaporative losses and making Lake Wichita a more drought resistant lake.

The quality of fishing is directly attributable to the quality of fisheries habitat. The excavation will increase the storage capacity and provide the water essential for fish survival. Aquatic plants will be reestablished, rock piles installed to protect the shoreline from erosion and also provide quality fish habitat, development of brush piles and placement of artificial structures will also aid in increasing the quality of the fish population and help attract the fish to the angler by being placed strategically with the end user in mind. Artificial structures such as mossbacks will primarily be used due to their longevity; however pest mesquite plants and other fringing vegetation being removed as part of the wetland's re-construction may also be used. A submerged rock jetty will be installed to reduce wind erosion and to also provide excellent habitat for fish. Florida largemouth bass, Hybrid striped bass, white crappie, bluegill, redear sunfish, and channel catfish populations are to be re-established through stocking by the Texas Parks and Wildlife Department. The combination of fish restocking and diverse habitat types, strategically placed, will aid in making Lake Wichita a great fishery again.

Over 81 hectares of wetlands and aquatic vegetation plantings are planned and will be strategically placed throughout Lake Wichita to maximize their benefits to water quality, wildlife viewing, the ecosystem, hunting, and fish and wildlife populations.

The plan for Lake Wichita includes the development and refurbishing of four boat ramps, four jetties extending out into the water (which also serve to protect the shoreline from erosion) and three floating fishing piers to provide access to the lake.

An engineering firm has been contracted to finalize the approval permits to drain the lake and conduct the excavations for submission to the US Corps of Engineers. It is anticipated that this work will be completed in late 2016.

The next and most difficult action will be to source the funding for the project which is estimated to require approximately $55 million dollars. There has already been extensive media coverage for the project and the Committee is now focusing their message on generating funding from the community.

Outcomes

The project is currently in the planning and approvals process so no outcomes have yet been derived. However, a report was commissioned from Midwestern State University on the potential economic impact of the proposed revitalisation of Lake Wichita (Martinez 2015). The evaluation predicts that more than $300 million and 11,800 jobs will be generated for the local community each year for the 10 years following project completion from increased retail sales. It was also anticipated that the lake will garner 250,000 hours annually of recreational activity that will bring in another $5 million per year to the local community.

Merchandise has been great for getting the message across to the general public

Costs

The total cost of the revitalization project is estimated to be $55 million. The largest cost component is the $40 million required to excavate the accumulated sediment and re-sculpture the bottom topography. The funding will come from a variety of sources including local, state and federal government, corporate, and foundation grants and donations from individuals. There are several wealthy philanthropists in the Wichita Falls area who have expressed interest in contributing sizeable donations. A strong fund raising campaign is currently underway.

Governance

In 2013 the Wichita Falls City Council created the Lake Wichita Study Committee (comprised of Wichita Falls and Lakeside City citizens, local business representatives, elected officials and city staff) and charged the committee with the task of developing goals and recommendations for recreation and non-recreation uses of water, shoreline, public safety, maintenance, and commercial development of the area. The name of the committee changed to the Lake Wichita Revitalisation Committee in 2014 and they have developed a Lake Wichita Revitalization Master Plan and are driving the project forwards. While the City of Wichita Falls owns Lake Wichita, the revitalization project is under the direction of five partners – Friends of the Reservoirs - Lake Wichita Chapter, Lakeside City, City of Wichita Falls, Texas Parks and Wildlife Departmengt, and the Wichita Falls Area Community Foundation.

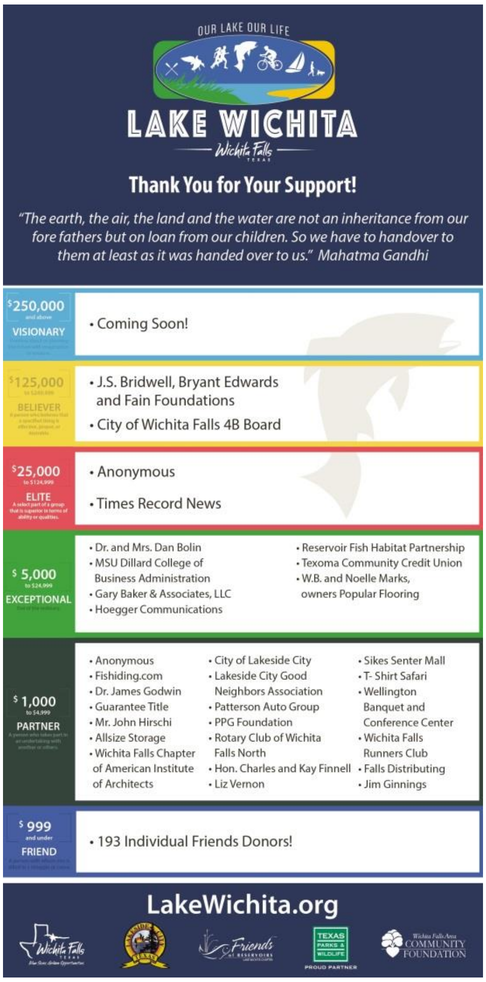
The project partners working together include both Government and non-profit entities. This structure enables the project to be eligible for a wider range of grants and also gives individuals the ability to donate directly to Government or the non-profit entity depending on their desires. Donations to non-profit entities may be applicable as a tax deduction in the USA and thus may be more enticing for corporate donors.

The Lake Wichita Revitalisation Project has gathered key groups to work together to share the enormous task of making Lake Wichita into a recreational fishing destination again. Partnerships are split into two categories; Principle Partners and Project Partners. Principle Partners are those entities whose partnership supports the Lake Wichita project as a whole, while Project Partners are focused on a specific element of the Lake Wichita project. The gathering of partners, with diverse skill sets, resources, and points of view, brought together with a common vision and goal helps to ensure the success of this holistic community revitalisation. The efforts are coordinated through the City of Wichita Falls' Lake Wichita Revitalisation Committee.

The Principle Partners for Lake Wichita are the City of Wichita Falls, Lakeside City, Texas Parks and Wildlife Department, Wichita Falls Area Community Foundation, and the Lake Wichita Chapter of Friends of Reservoirs.

Project partners will be identified once the specific aspects of the Master Plan are implemented.

A high level of importance has been placed on recognising the efforts of people who have assisted the project. A list of donors is printed regularly in the local newspaper to provide recognition of their contribution. The earlier an individual or company has donated, the more times their name appears in the paper.



One of the recognition advertisements in the local newspaper for donors to the project

Relevance to Australia

The project to revitalize Lake Wichita provides insight into how restoration and enhancement projects should be planned. The governance and funding model contain not only extensive stakeholder involvement, but also stakeholder ownership of the problems and financial investment in the solutions. Resources for fisheries management and habitat enhancement in Australia are very limited. Large scale projects will require significant investment from local stakeholders, not just investment from state and federal government. The local councils at Wichita Falls and Lakeside City have seen the potential benefits and are willing to invest to achieve long-term benefits. The Lake Wichita project also highlighted the importance of engaging a broad range of stakeholders to increase the potential value of lake restoration and develop broader support for a project. A key focus may be to develop a great recreational fishery for the lake, but by identifying the benefits to other user groups the costs for some common activities can be shared and the net benefit far greater. In order for any large scale reservoir fisheries restoration program to occur in Australia, it is likely that investment from other user groups will be necessary.

Costs and benefits of habitat enhancement

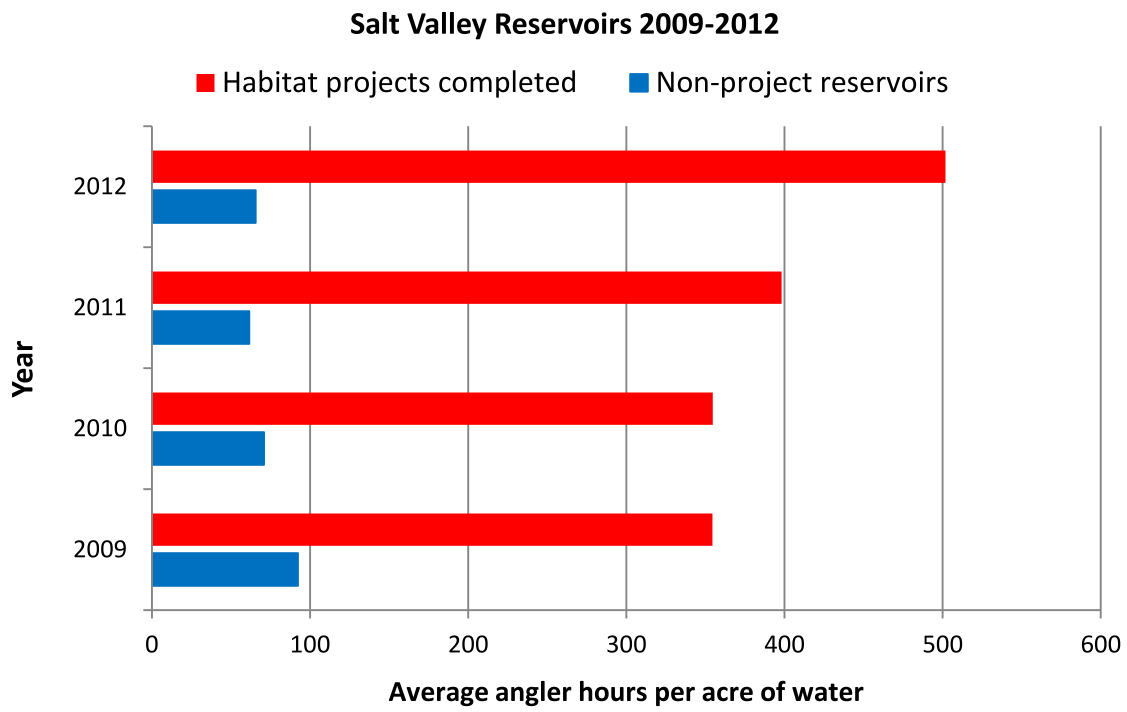
Despite habitat enhancement being commonly undertaken in reservoirs across the USA, few examples of the economic analysis of project benefits versus the costs could be found. Raising funds for large-scale rehabilitation projects can be difficult; thus, it is prudent to assess the outcome of these efforts. One goal of adding habitat structures in an enhancement project is to improve angler catch rates. Logically, an increase in angler catch rates increases the popularity of the fishery and thus increases the economic benefits derived from the lake. Below are several examples of different approaches that have been taken to assess the cost versus benefit of improving reservoir fisheries through habitat enhancement.

The economic impact assessment of the Lake Havasu Fisheries Improvement Program by Anderson (2001) was one of the first to demonstrate that significant benefits to the local economy can be generated by large-scale habitat improvement programs. The resulting increase in fishing activity, and associated fishing related expenditures in the local area, have produced significant, long term socioeconomic benefits to the local area, including increases in employment, income and tax revenues. The improved fishery was providing an annual economic benefit within the local area of $51.5 million and 1289 jobs. Importantly, $33.8 million of this was generated by non-residents who were bringing their tourism dollars into the region. Resident anglers' expenditures generated an additional $17.7 million in value-added, 639 jobs, and $2.6 million in state and local tax revenues. The cost of the project for the first 10 years was estimated to be only $14 million dollars, thanks largely to the huge amount of volunteer labour (Jacobson & Koch 2008). All figures are quoted in US dollars.

Unfortunately no assessment of the fisheries value was conducted as part of the Environmental Assessment prior to the improvement program. It is therefore difficult to obtain an exact figure for the increase in the economic value attributed to the fisheries improvement program. The angling pressure on the lake almost quadrupled (43,000 to 175,000 angler use days per year) between 1989 and 2001 following habitat enhancement. Assuming that daily expenditure of the anglers and the ratio of resident to non-resident anglers remained constant, a rough estimate of the total annual economic value of the Lake Havasu fishery prior to habitat enhancement would be $12.7 million. Comparing the annual economic values between 1989 and 2001 reveals a difference of approximately $33.8 million. The increase in angling effort cannot be solely attributed to the fisheries enhancement program; however it is most likely the largest factor. The total cost of the habitat enhancement program was only $14 million and therefore would have likely taken less than 1 year to be recovered from the improved fishery. The economic benefits are expected to last into the foreseeable future with relatively low ongoing program and structure maintenance costs.

A more basic approach was used to estimate the increase in economic value from habitat enhancement in Cottonmill Lake, Nebraska. Spirk *et al.* (2008) determined angler visitation rates before and after the rehabilitation of the lake's fishery. The derived economic benefits from the rehabilitation project were estimated as the difference in annual angler visitation multiplied by the average daily expenditure. Survey data suggested the average angler fishing in Nebraska spent $66 per day (USFWS 2006) and that angler visitation increased from 394 to 5,561 angler days. The increase in annual expenditure works out to be approximately $341,000. The cost of the rehabilitation project was $1.5 million and Spirk *et al.* (2008) estimated that expenditures by anglers would surpass the lake restoration cost within a few years.

In the reservoirs of Salt Valley, Nebraska, angling effort has increased markedly in reservoirs where habitat rehabilitation and enhancement projects have been conducted. Angler effort (average angler hours per acre) between 2009 and 2012 was up to 7 times higher in reservoirs where habitat projects had been conducted compared to sites where no works were undertaken (data collected by Dustin Martin, UNL and provided by Mark Porath, NGPC). Unfortunately no economic information was collected during these creel surveys, but the increased angler visitation and effort would translate into increased angler expenditure in local areas and generate significant economic benefits to local communities.



Angler effort in Salt Valley Reservoirs, Nebraska between 2009 and 2012. Note the significant additional angler effort in reservoirs where habitat projects had been completed, compared to those where no projects were undertaken (data collected by Dustin Martin, UNL).

Construction and installation costs for different habitat structures are also rarely reported in detail. As part of the Table Rock Lake project, Allen *et al.* (2014) included details of the cost for installing pine trees, cedar trees, hardwood trees, stumps and rocks. These provide an excellent basis to discuss the relative cost benefits of these habitat materials. The components used to construct synthetic structures are typically low cost. Where possible, projects have utilised recycled or donated materials to minimise construction costs. Unfortunately this made data on construction costs difficult to find.

Estimated installation costs (in USD) associated with five different habitat structure types. Habitat materials were donated and costs associated with transporting the habitat material to the access point staging areas were not considered. Adapted from Allen* et al. *(2014)

Habitat Structure Type	Supply costs	Installation Time (hours × # staff)	MDC staff. ($/hr)	Contractor Costs ($/hr)	Total cost per structure
Cedar	50.00	2 × 2	15.00	78.00	$266.00
Pine	50.00	1.5 × 5	15.00	NA	$162.50
Hardwood	50.00	2 × 2	15.00	78.00	$266.00
Stump	0	2 × 1	15.00	656.00	$1,342.00
Rock	0	2.5 × 1	15.00	656.00	$1,677.50

Fish habitat enhancement in reservoirs has the potential to improve the recruitment of juvenile fish. The majority of Australian freshwater recreational species do not breed in impoundments. Therefore, stocking programs are essential to maintain recreational fisheries and it is important to optimise stocking strategies to avoid wasting money and effort. Since 2006 more than 65 million fish have been stocked throughout New South Wales, Victoria and Queensland alone. A frequent concern of fish stocking groups and fisheries managers has been the probable loss of stocked fry and fingerlings to predators (Hutchison *et al.* 2006). Predation and mortality of fingerlings is often highest immediately following release, particularly where habitat structure is limited. Various studies have shown that the presence of aquatic plants can increase survival of juvenile fish (Durocher *et al.* 1984, Miranda & Pugh 1997). Hutchison *et al.* (2014) demonstrated that juvenile Murray cod and golden perch showed strong attraction to rock rubble and aquatic macrophytes. The installation of brush structures, rock rubble and other structural habitats can also enhance the survival stocked juveniles (Miranda & Hubbard 1994, Lindberg 1997, Okumura 2002). Increasing the survival of stocked fish leads to more fish surviving to legal size for the same initial investment. Given the high level of annual investment to restock Australian impoundments, even small increases in juvenile survival will provide significant cost savings. Comprehensive habitat enhancement projects in Australian reservoirs would not only improve habitat for mature fish, but also increase the number of stocked fish surviving through to legal size. Additionally, if habitat installations benefit small, non-angling species that breed in reservoirs, then the increased food supply may also benefit the fishery through provision of improved growth rates.

Conclusions

There is a convincing body of evidence from the USA that suggests habitat enhancement in reservoirs can positively influence impoundment fisheries. In Australia many reservoirs were cleared of structure prior to filling or have suffered habitat degradation with reservoir aging. Most of these reservoirs are also primarily used to supply water for irrigation or domestic supply, with fisheries and recreation a lower priority. Many impoundment fisheries in these systems therefore have developed with fluctuating water levels, scarce amounts of aquatic vegetation and limited structural habitat. The installation of fish habitat enhancement structures is capable of helping counter these issues.

The installation of habitat structures can significantly improve angling by attracting fish to locations that anglers can target. Habitat enhancement frequently improves angler success, increases catch rates and has in some cases improves the mean size of fish caught. In highly degraded systems completely re-engineering reservoir environments or improving aquatic vegetation coverage can lead to improvements in primary production and carrying capacity, and revitalise the fishery. This process is very expensive, lengthy and time consuming. The installation of fish attracting habitat has the potential to achieve similar results; however the relationship between structure type, numbers and location and primary production still needs further research.

Although many recreationally targeted fish species in Australian impoundments rely on stocking to sustain their population, artificial spawning habitat could improve the abundance of certain naturally spawning species if the necessary habitat is limiting. Installation of suitable spawning habitat could benefit eel-tailed catfish (gravel beds), possibly freshwater cod species (pipes, hard structures) and snub-nosed garfish (macrophytes or macrophyte substitutes) in Australian impoundments.

Significant long-term financial, social and environmental benefits can be generated by improving or restoring reservoir fisheries. In successful projects in the USA, the cost of rehabilitation is often recovered after only a few years, but benefits continue to persist. As the Australian population continues to grow and more pressure is placed on our fisheries resources, improving reservoir fisheries will help protect wild river and estuary fish stocks from over-exploitation by providing alternative sources of fish for anglers who do not practise catch-and-release. Re-invigorating and enhancing reservoir fisheries will also increase angling opportunities and generate economic benefits to regional communities that rely heavily on impoundment fisheries for tourism.

Research and knowledge on habitat enhancement of impoundments to improve fisheries is in its infancy in Australia. Much of the knowledge on the outcomes of reservoir habitat enhancement projects comes from overseas. Research is needed to verify that the same principles will deliver the similar results for Australian species and conditions. Further investigation is required to optimize habitat improvement efforts in reservoirs, but with the knowledge gained to date, significant improvements in fishing and fish production can be made if undertaken properly.

The findings from my Churchill Fellowship will be disseminated to the leading fisheries researchers, managers and angling organisations in each Australian state that were contacted as part of the Australian prioritisation survey undertaken before the visit to the USA. Stories from the Fellowship will be submitted to the DAF internal website and several e-zines, such as Newstreams and

Freshwater Fisheries News. A copy of the report will be sent to the Australian Fish Habitat Network for dissemination to its members. The report will also be provided to all of the organisations and individuals visited in the USA to solidify the international relations developed and encourage further dialogue and knowledge exchange. Whilst in the USA coverage in three television and four newspaper interviews helped raise the profile of the importance of habitat enhancement and the Churchill Fellowship Program.

Recommendations

Management structure and planning

1. Management objectives must be clearly defined at the commencement of a habitat enhancement project to determine the most appropriate strategies and techniques to be used and to develop realistic targets. Clear distinction needs to be made whether the project is targeting an increase in fish abundance, or aggregation of fish to improve angler catch rates. It is recommended that all Australian projects establish clear strategic objectives and targets early in the planning process.

2. Small habitat enhancement projects in Australia should be able to be run entirely by State fisheries or wildlife management agencies, with input and assistance from key stakeholders. Larger habitat enhancement projects will most likely involve multiple partners and thus should include a steering committee comprising representatives of key stakeholder groups as part of their governance model.

3. Labour costs can be one of the greatest impediments to habitat enhancement. Volunteer support is extremely important to keep budget costs low and ensure long-term objectives are met. It is highly recommended that volunteer labour be utilized to construct and deploy habitat where possible to minimize the funding required for projects.

4. Prior to the commencement of any reservoir fishery improvement project the current status of the fishery and habitat availability must be assessed. This baseline assessment will identify key impediments and deficiencies that need to be addressed in order for the fishery to be improved. The information collected will enable specific and targeted project objectives to be developed and form baseline data against which project progress and success can be measured.

5. It is also strongly recommended that surveys be repeated after the habitat enhancements have been undertaken to assess their effectiveness and guide future activities.

Habitat construction, deployment and evaluation

6. A diversity of habitat structure types and sizes should be deployed to create a range of different habitats. This will benefit the greatest number of fish species and size classes.

7. All habitat enhancement activities need to be based upon the target species' behavior and habitat requirements. Most types of habitat structure will attract fish. Where possible, it is recommended that projects make opportunistic use of materials to decrease construction costs, particularly if funding is limited. Recycled or waste materials should be used where suitable to

keep costs low and minimize wastage.

8. If natural materials are used in the construction of habitat structures, they should be as freshly cut as possible. Fresh vegetation has a higher moisture content making it denser and therefore requires less weight to sink and anchor in place. Additionally, if trees are felled for habitat, older and dead trees are more prone to explode when the hit they ground, reducing their effectiveness as habitat.

9. If rock reefs are utilized, they should be moderate to large in size and aim to achieve significant vertical profiles to be most effective. A mixture of rock sizes should be used to create a variety of interstitial space sizes.

10. Habitat structures should have as much structural complexity as possible and not contain large open voids. Structures with large voids attract and hold less fish. Structural complexity can be increased by the addition of finer materials, such as brush, into the voids.

11. Careful consideration needs to be given to the size of the interstitial spaces in fish habitat structures and the types of fish that will utilize them. In general, structures with smaller interstitial spaces should be used to benefit small fish species or juveniles of larger species. More open structures are more suitable to for attracting large fish and are preferred to fish by anglers because they are less prone to snagging hooks.

12. It is recommended to use hard plastic structures where the goal is to purely aggregate fish for anglers. These structures are typically easy to construct and deploy at high densities and are more resistant to snagging hooks. This makes them excellent for aggregating fish into areas for shore based anglers. Where this is the objective, the structures should be placed just out of casting distance or floating piers.

13. The use of sheets of plastic, shade cloth and plastic fencing is not recommended because they can detach from supporting structures and become a navigational hazard.

14. The use of non-polluting hard plastic and rock structures is recommended where there are concerns on the impact on water quality from the introduction of fish habitat structures. These materials will not degrade and introduce additional nutrients and fine debris into the water.

15. Where possible, the use of project-constructed habitat is recommended over commercially available fish habitat structures for large-scale projects, unless the commercial products are donated or sponsored. Commercially produced habitat is generally relatively small in size and can be expensive to purchase. Installing sufficient numbers to achieve the desired structure density can be prohibitively expensive outside of small impoundments.

16. Environmentally re-engineering reservoirs is extremely effective at restoring aquatic ecosystems and improving recreational fisheries. However, the process is extremely costly and requires lowering water levels significantly. It is therefore recommended that this approach is only used for highly degraded impoundments that are not vital water storages, and would be particularly suited to the degraded lakes commonly found within housing developments.

17. Opportunistic advantage should be taken during periods of low water level to install fish habitat structure. Low water levels enable the use of four-wheel drives, tractors, excavators and dozers to rapidly deploy a wide range of structure types.

18. It is recommended that specialist equipment and heavy machinery be used during larger habitat enhancement projects to increase transport and deployment efficiency. In particular, it is recommended that specialized habitat barges be used to transport and deploy habitat structures. These vessels allow greater numbers and sizes of structures to be deployed more safely and efficiently. It is recommended that the barges remain of trailerable size to enable there use in multiple projects and at multiple sites.

Habitat location

19. Habitat structures should be installed to supplement and enhance existing structure in the impoundment. Recommended locations include near underwater points, steep changes in the bottom topography, degraded stands of timber and adjacent to aquatic vegetation. Structures should be placed in a variety of depths to suit habitat requirements of the target species throughout the year.

20. The majority of habitat should be installed above the thermocline depth of the reservoir to ensure it can be accessed by fish throughout the year. Some structure can be placed in deeper water to provide habitat during winter when the thermocline is deeper or non-existent.

21. Fish habitat structures should be placed at a sufficient depth (>1.5 metres to the top of the structure) that they will not become a navigational hazard or smothered by aquatic vegetation.

22. It is highly recommended that fish attraction also sites be created in areas accessible by shore-based anglers. Shore-based fishing access points are very limited at most impoundments and attracting fish to these areas will increase angler satisfaction and catch rates.

23. The locations of habitat enhancements within a reservoir should be made readily available to the public, including information on the co-ordinates, structure type, water depth and deployment date. It is recommended that interactive online maps or mobile phone apps be created to allow anglers to locate and target habitat structure sites whilst on the water. The use of buoys to provide visual identification of these sites is also recommended where they do not pose a navigational hazard. Easy access to information on the locations likely to hold fish will be especially useful to visiting anglers, tourists renting boats, or anglers who do not have sounders on their boats. This may attract more visiting anglers to a reservoir.

Fluctuating water levels

24. Where water levels fluctuate significantly, it is recommended habitat structure be installed across a wide range of water depths to ensure fish always have access to sufficient habitat. Lines of structure running at an angle to the shoreline are an effective way to achieve this. Structure closest to the high water line should be made of durable materials (rock, hardwood timber or hard UV stabilized plastic) so that it does not degrade if frequently exposed to air.

25. In reservoirs with fluctuating water levels it is also recommended that the effectiveness of

seeding grass beds or fast growing annual plants on the bank during water drawdown be evaluated under Australian conditions. This technique has the potential to provide significant benefits to fish growth and reservoir productivity for a relatively low cost. The planted vegetation also helps reduces shoreline erosion.

Economics

26. Detailed costing data should be collected for the construction and deployment costs for each habitat type and deployment strategy. This information will enable cost-benefit analyses to be accurately conducted to identify the most cost-efficient strategies for improving the fishery.

27. It is also recommended that an economic assessment of the reservoir fishery's value be conducted prior to the commencement of any on-ground works and repeated after the habitat enhancement activities have been completed. The follow-up assessment should be conducted several years after habitat installation so that there has been appropriate time for a biological response to occur. The information from these assessments will provide valuable data on the economic changes to the fishery's value brought about by the habitat enhancement and permit estimation of the project cost recovery time.

Future research

28. There are many knowledge gaps that need to be addressed regarding the use of habitat enhancement to improve reservoir fisheries. Research is needed to improve the effectiveness and optimize return on investment. Priorities areas for research include:

    a. Utilization of different habitat enhancements by key recreational fish species in Australia
    b. Determining the quantity of habitat enhancement required to achieve significant fisheries improvements and what the most cost effective combination of techniques to accomplish this
    c. Deployment strategies for habitat structures, including density and deployment configurations

It is strongly recommended that a number of pilot projects be undertaken in Australian reservoirs before broad-scale use of habitat enhancement is adopted. Habitat enhancement has the potential to generate significant, long-term benefits, but ascertaining the most effective strategies for Australian conditions could save significant investment in ineffective large-scale projects and avoid stakeholder disengagement.

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