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Memorandum
Agenda Changes/Supplemental Packet

TO:	PLANNING COMMISSION
FROM:	RENEE KRAUSE, DEPUTY CITY CLERK II
DATE:	FEBRUARY 1, 2023
SUBJECT:	SUPPLEMENTAL

9. PLAT CONSIDERATION(S)

9.A. Forest Trails Subdivision Preliminary Plat

Public Comment received

From: Melissa Jacobsen
To: Renee Krause; Rick Abboud
Subject: FW: Public Comments for Forest Trails Subdivision Preliminary Plat
Date: Wednesday, February 1, 2023 7:58:36 AM
Attachments: 2023_01_31_CCB_Forest_Trails_Prelim_Plat_Comments_Submitted.pdf

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For the planning commission, I'll forward to Council.

Thanks!

From: Joel Cooper <joel@kachemaklandtrust.org>
Sent: Tuesday, January 31, 2023 5:54 PM
To: Melissa Jacobsen <MJacobsen@ci.homer.ak.us>
Cc: Marie McCarty <marie@kachemaklandtrust.org>; Dan Marsden <dan@kachemaklandtrust.org>
Subject: Public Comments for Forest Trails Subdivision Preliminary Plat

CAUTION: This email originated from outside your organization. Exercise caution when opening attachments or clicking links, especially from unknown senders.

Hi Melissa,

As per our phone conversation, I would like to submit the attached written comments for the Forest Trails Subdivision Preliminary Plat. Please distribute these comments to the City of Homer Planning Department, Planning Commission, Mayor and City Council. I will be attending the Planning Commission Worksession and Public Meeting accordingly.

Please let me know if you have any questions. Please acknowledge in this email that you have received these comments.

Many thanks!

Joel Cooper
Stewardship Director/IT Specialist
Kachemak Heritage Land Trust
315 Klondike Ave.
Homer, AK 99603
(907) 235-5263 (Main Office)
(907) 235-5331 (Direct Line)
joel@kachemaklandtrust.org

KACHEMAK HERITAGE
LAND TRUST

ACCREDITED LAND TRUST ACCREDITATION COMMISSION

January 31, 2023

Homer Planning Commission
491 East Pioneer Avenue
Homer, AK 99603

Re: Kenai Peninsula Borough parcel # 179-030-21, a 4.85-acre parcel located at 1441 East End Road, Homer, Forest Trails Subdivision Preliminary Plat Review

Dear Planning Commission Members,

I am writing on behalf of Kachemak Heritage Land Trust (KHLT) as an adjacent landowner to the above-referenced parcel. KHLT is the owner of the Calvin & Coyle Woodland Park containing six parcels totaling 28.67 acres that is depicted in Figure 1 below. The northwestern boundary of parcel # 17903056 is adjacent to the proposed Forest Trails Subdivision.

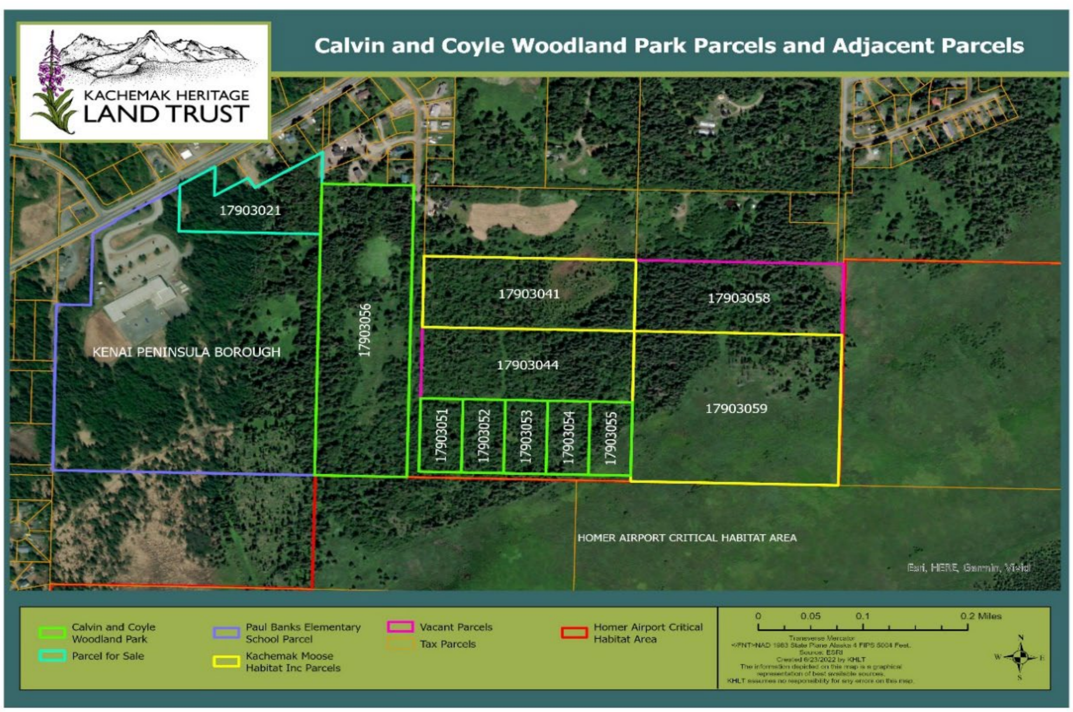

Figure 1: Calvin & Coyle Woodland Park and Adjacent Parcels

KHLT is not opposed to the development of private property but wishes to express its concern about the impact of the proposed development adjacent to one of its Ambassador Properties and hopes that there is an opportunity for mitigation of potential adverse impacts to the community-loved trail. Consensus of this region's ecological importance is best described in the Homer Soil and Water Conservation District's (HWSCD) 2013 City of Homer (COH) Beluga Planning Atlas, which labeled the Beluga watershed as the "*Wetland Heart of Homer"* (see Figure 2). KHLT submits its comments as part of its public comment for the KPB and COH mayors, councils, planning commissions and land developers to take into consideration when reviewing preliminary plats.

Figure 2: Bear Creek/Beluga Slough Watershed (*The Wetland Heart of Homer*). Source: HSWCD Beluga Planning Area Volume 1 (8/26/2014)

KHLT's primary goal for the Calvin & Coyle Woodland Park is to manage the land to benefit wildlife habitat and for public benefit. This includes preserving the surface resources, vegetative cover, wetland, hydrologic and other water quality values of the property in its natural condition. The KHLT property is primarily a wetland discharge slope with a small area identified as wetland kettle (Source: KPB). KHLT protects the natural resource values of the property in perpetuity by prohibiting any use of the property, including over-use, that conflicts with these inherent conservation values.

KHLT manages the 1.5 mile out and back trail with a lollipop loop on the southern part of the property (see Figure 3). KHLT works with the Kenai Peninsula School District to manage the trail (see Figure 2) on their parcel and the Alaska Department of Fish and Game (ADF&G) who manages the adjacent Homer Airport Critical Habitat Area (HACHA).

In addition, KHLT is bound to a North American Wetlands Conservation Act ("NAWCA") Grant Agreement which includes ensuring the long-term conservation of the property in accordance with the

Grant Agreement and obtaining the consent of the U.S. Fish and Wildlife Service (USFWS) prior to the conveyance of any property interests.

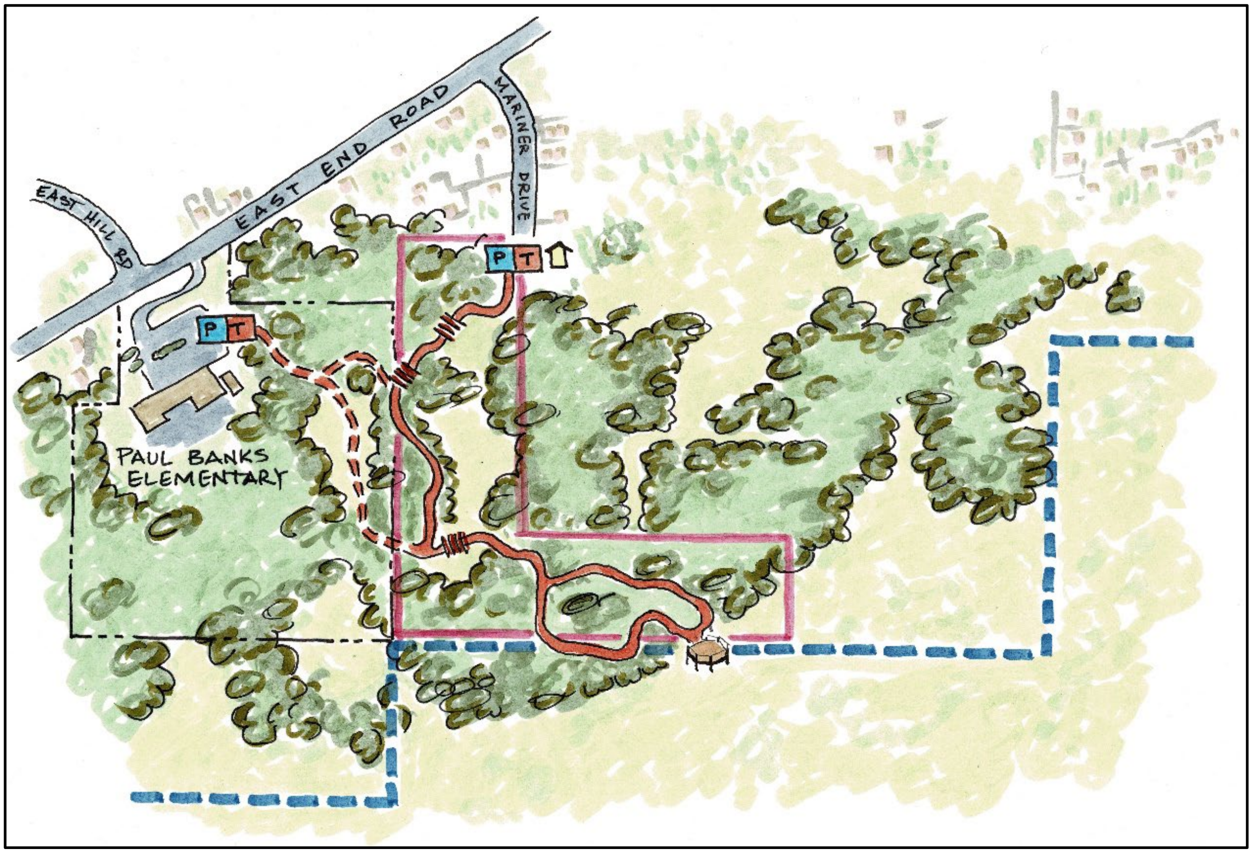

Figure 3: Calvin & Coyle Woodland Park Trail System and Adjacent Paul Banks Elementary Trail System

KHLT manages 28 conservation easements totaling 2,496.59 acres and 18 fee-owned parks and preserves totaling 1,335.44 acres across the Kenai Peninsula. When managing these lands KHLT finds adjacent developments like these can impact the conservation values of these properties through unauthorized motor vehicle use, trail development, and tree cutting. An increase in littering also occurs. These developments also increase the potential for the spread of invasive species.

KHLT has the following concerns with the proposed plat:

- Increased impervious coverage upgradient to the Calvin & Coyle Woodland Park will affect the hydrology of the wetlands ecosystem of the park. The proposed development is very condensed with 13 lots ranging from 0.231 acres (10,051 ft^2) to 0.381 acres (16,596 ft^2) in a 4.85 acre parcel. A 60-foot-wide ROW totaling 1.087 acres (47,347 ft^2) bisects the property ending with a cul-de-sac and 44.84 feet of land separating the cul-de-sac from the western boundary of KHLT parcel # 17903056.
- Inadequate riparian buffer and culverting of the 625 linear feet of stream channel running through the site that was documented by the U.S. Army Corps of Engineers in their October 28,

2022 jurisdictional determination. This channel makes its way through Calvin & Coyle Woodland Park and terminates in the HACHA.

- Unauthorized trail development, motorized vehicle use, and tree cutting in the Calvin & Coyle Woodland Park.
- Increased potential for the spread of invasive species.
- Increased public use of Calvin & Coyle Woodland Park. This development will have a direct economic impact on KHLT's management of this park due to an increased potential for unauthorized motor vehicle use, trail development, tree cutting, and littering.

According to the COH Planning Department, the Forest Trails Subdivision Preliminary Plat parcel is zoned Rural Residential and would need to follow level one site development standards 21.50.020 Site development standards – Level one. These standards are found on the Homer City Code website: https://www.codepublishing.com/AK/Homer/#!/Homer21/Homer2150.html#21.50.

Based on the information and concerns described above, KHLT proposes the following recommendations as they pertain to the Forest Trails Subdivision Preliminary Plat.

- Reduce the size of the ROW to minimize the amount of impervious coverage.
- Require a minimum 50 feet of undisturbed natural forest riparian buffer of existing native vegetation on each side of the 625 linear feet of stream channel. Buildings and other features that require grading or construction must be set back at least 10 additional feet from the edge of the buffer. The Bridge Creek Watershed Protection District requires a 50 foot buffer. This stream channel drains into one of Homer's most important wetlands, "*The Wetland Heart of Homer*", and should require similar standards.
- Use level two site development standards to help mitigate the impacts to the down gradient wetlands. These standards are found on the Homer City Code website: https://www.codepublishing.com/AK/Homer/#!/Homer21/Homer2150.html#21.50.
- Require the use of weed free gravel and soil to reduce the chance of introducing invasive species.

<u>Subdivision Process</u>

KHLT was first contacted about the Forest Trails Subdivision Preliminary Plat on 1/9/2023 when staff from the City's Planning Department, contacted KHLT's Executive Director (ED) via email requesting a copy of the conservation easement for the property east of Paul Banks Elementary (Parcel # 17903056). The Executive Director asked that I follow up on this request.

I spoke with the City's Associate Planner on 1/9/2023 and explained to her that there was not a conservation easement held on parcel #17903056 and that this was one of six parcels that makes up the Calvin & Coyle Woodland Park. I also advised her that KHLT is required to draft a management plan as a nationally accredited land trust. KHLT completed a revision of this management plan and it was Board approved in August 2022.

We discussed the Forest Trails Subdivision Plat dated 12/2022 depicting the 60 foot ROW dead ending up against KHLT parcel #17903056. The Associate City Planner provided this plat via email during our discussion. The Forest Trials parcel is adjacent to the northwest corner of Calvin & Coyle Woodland Park. During this discussion the Associate City Planner mentioned that the Army Corps did a wetlands determination on the Forest Trails subdivision and provided me a copy of this determination via email on 1/10/2023. This determination identifies 625 linear feet of stream channel running through the Forest Trails Subdivision parcel. This steam runs year-round and after it exits the 4.85 acre Forest Trails Subdivision parcel, it makes its way through the Kenai Peninsula Borough (KPB) Paul Banks Elementary School parcel, to KHLT's Calvin and Coyle Woodland Park, and then terminates in the Homer Airport Critical Habitat Area (see Figure 7 flow paths map from the Kachemak Bay National Estuarine Research Reserve (KBNERR)). I told the Associate City Planner that KHLT would submit comments as it pertained to the Forest Trail Preliminary Plat and the potential impacts to the Calvin & Coyle Woodland Park and that I may have more questions.

Figure 4: Tree cutting activity along the western border of KHLT parcel # 17903056 and the Forest Trails parcel. Arrows point to surveyed boundary stake and flag. KHLT's parcel lies to the left of this line and the Forest Trails parcel to the right. (Source: KHLT, Photo taken 1/25/2023)

KHLT’s Executive Director informed me on 1/20/2023 that tree cutting had begun on Forest Trail Preliminary Plat parcel. I viewed the property on 1/24/2023 from East End Road and confirmed that tree cutting had begun and several trees in the center of the property had been felled.

KHLT staff drafted comments to be reviewed by its Land and Easement Committee at its meeting on 1/24/2023 to solicit additional input as to how this subdivision development might impact the hydrology and management of the Calvin & Coyle Woodland Park. KHLT received a Public Notice of Subdivision in the mail on 1/24/2023 and this notice included a Forest Trails Subdivision Preliminary Plat dated 1/2023 depicting the 60 foot ROW ending with a cul-de-sac and 44.84 feet of land separating the cul-de-sac from the western boundary of KHLT parcel # 17903056 and this was provided to the Committee prior to the meeting. The Vicinity Map included with this Public Notice depicts Calvin & Coyle Woodland Park and Paul Banks Elementary School on a map adjacent to the subdivision parcel. The Committee recommended that stewardship staff do on the ground documentation of the northwestern boundary of KHLT parcel # 17903056 and the stream corridor on 1/25/2023

On 1/25/2023 KHLT's Stewardship Director and Coordinator made a site visit to KHLT parcel # 17903056 to document activity along its northwestern border and trace, viewed from KHLT's property, the steam channel described in the 10/28/2022 Army Corp Wetlands Determination (POA-2022-00431) from the Calvin & Coyle Woodland Park to the southern boundary of the Forest Trails Subdivision parcel. Figure 4 documents activity along the western border of KHLT parcel # 17903056. It appears that all trees in this area on the Forest Trails Subdivision parcel were cut up to the border of KHLT parcel # 17903056 and some of the felled material fell onto KHLT's parcel # 17903056. KHLT is reviewing this activity as it pertains to third-party violations.

Figure 5 below looks north into the Forest Trails Subdivision Preliminary Plat parcel from the KHLT parcel at the Army Corps determined 625 linear feet of stream channel and the vegetation removal that had already taken place in the buffer zone of the stream channel.

Figure 5: Looking north from the Paul Banks Elementary School parcel at the 625 feet of stream channel running through the Forest Trails Preliminary Plat parcel. (Source: KHLT, photo taken on 1/26/2023)

During KHLT's site visits on 1/25 and 1/26/2023, on KHLT's land, its stewardship staff attempted to walk from the second bridge shown in Figure 3 to the southern boundary of the Forest Trails Preliminary Plat parcel to spatially map the stream channel. KHLT staff could see the channel corridor connecting from Calvin & Coyle Woodland Park Nature Trail Bridge #2 to the southern end of the 625 linear feet of stream channel documented in the Army Corps wetlands determination. However, staff could not walk the channel because 5 moose were browsing and bedded down in the stream corridor. KHLT staff again attempted to walk the channel on 1/26/203 and encountered the same 5 moose defending this stream channel that feeds into the HACHA (Figure 6). Figure 7 shows the estimated flow paths of stream channels within Calvin & Coyle Woodland Park and adjacent parcels.

Figure 6: Arrow points to moose bedded down on stream corridor bank.

After reviewing the Public Notice of Subdivision provided by the City of Homer, speaking to the KPB Department and the City of Homer Planning Department, KHLT reviewed the regulatory process in both KPB and COH code for creating a subdivision. The site development activity took place prior to the Public Hearing and due date of the Forest Trails Subdivision Preliminary Plat Public Comments. KHLT is concerned that the order of sections of HCC are being implemented in an order that allows significant and potentially impactful development before the public comment period and the public hearing, rendering some of the public input essentially moot.

KHLT requests that 21.50.030 Site development standards – Level two be applied to this parcel to further protect the 625' jurisdictional stream and the down gradient properties. Most of the property's trees were cut down prior to the public hearing with an excavator with a tree cutting implement that has disturbed the topsoil. It is of concern to KHLT that 21.50.020 Site development standards – Level one, which are required for a zoned Rural Residential parcel[1], were not followed by the Homer Planning Department. The activity I observed has had an impact on the recommended buffer zone and compromised KHLT's public comments.

[1] https://www.codepublishing.com/AK/Homer/#!/Homer21/Homer2112.html#21.12 Web accessed on 1/31/2023.

KPB code 20.25.050 D requires that "*A vicinity map, drawn to scale showing location of proposed subdivision, north arrow if different from plat orientation, township and range, section lines, roads, political boundaries, and prominent natural and manmade features, such as shorelines or streams;.*"[2] be provided. The Vicinity Map [2] that KHLT received in the Public Notice of Subdivision did not depict the stream channel and the prominent natural (Figure 7) and manmade features (Figure 3). This stream runs year-round and after it exits the 4.85 acre Forest Trails Preliminary Plat parcel, it makes its way through the Paul Banks Elementary School parcel, to KHLT's Calvin & Coyle Woodland Park, and then terminates in the HACHA (Figure 7). These parcels will be impacted based on how this plat is approved. In addition, the Vicinity Map does not show the Homer Airport Critical Habitat Area, a critical parcel of this drainage. Although this is not adjacent to the Forest Trails Subdivision parcel, this is an important natural feature that could be impacted by development activities around the 625 feet of stream channel as it is down gradient. Without the required information on the Vicinity Map, those receiving notice have not been advised of the prominent natural features and may not consider commenting.

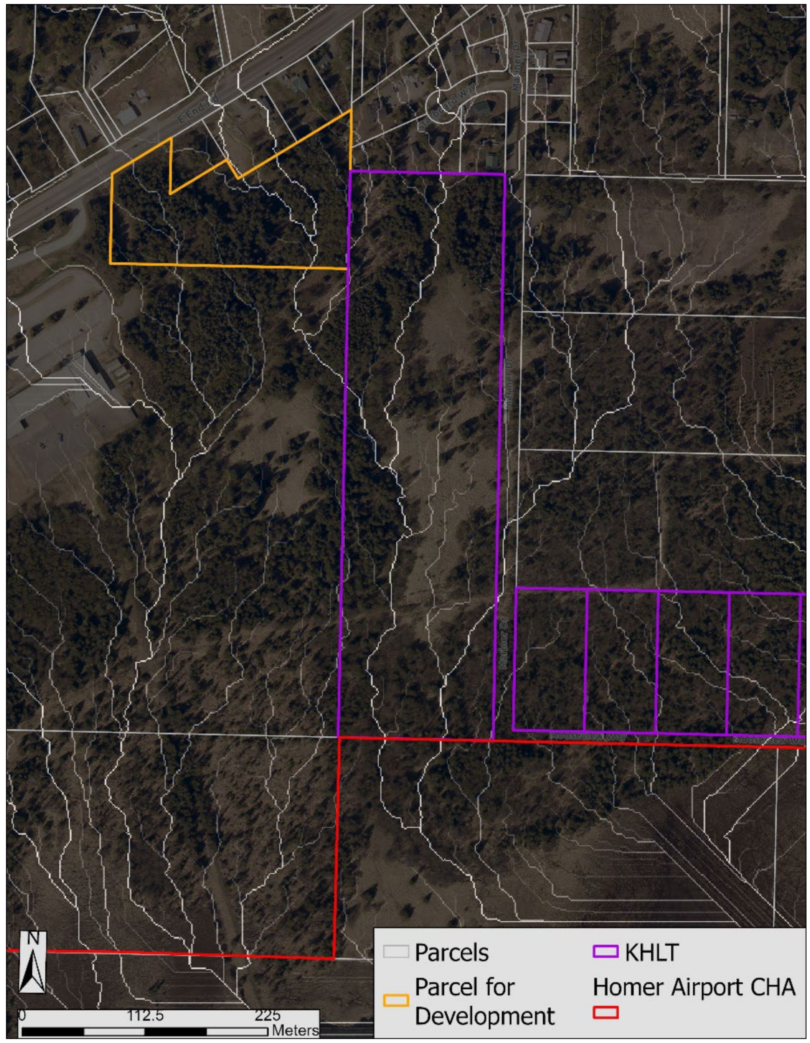

Figure 7: Estimated flow paths of stream channels within Calvin & Coyle Woodland Park and adjacent parcels (Source: Kachemak Bay National Estuarine Research Reserve 1/27/2023)

KHLT suggests that once the landowner submits a subdivision plat for COH Planning Department review and subsequent public hearing and comments that it was up to the City Planner to administer and enforce the Zoning Code[3]. It appears that HCC is silent as to when to administer and enforce 21.50.020 Site development standards – Level one during the plating process, which can make public comment occur too late in the process. Discretion could have been used to recognize that 21.50.020 Site development standards – Level one should be considered during the plating phase of the process as this was no longer a situation where a landowner can cut their trees on their private parcel of land but that a subdivision is being developed that can impact the adjacent landowners and the *prominent natural and manmade features* associated with adjacent parcels. KHLT requests that COH Planning Department work with the Homer City Council to draft HCC to make it explicitly clear as to when and what code to administer and

[2] The Vicinity Map is not the same as the Forest Trails Subdivision Preliminary Plat Map as per KPB code 20.25.050 D.
[3] https://www.codepublishing.com/AK/Homer/#!/Homer21/Homer2190.html#21.90 Web accessed on 1/31/2023

enforce during the plating phase of subdivision development so that both the developer and the public are clear about when and how the process will be administered when requesting preliminary plat approval.

Buffers

Within the City Code there is no clear definition of a *"Buffer"*. However, the concept of riparian buffers is not new. KHLT considers the riparian buffer of stream corridors a primary conservation value in the lands we protect and a main criteria considered in our due diligence process in stewarding land. Below is a cited definition of a *"Buffer"*.

"Buffers are, by definition, natural vegetation left along the banks of a water body in the course of conducting a land-disturbing activity. This definition implies that the buffer has a finite width, starting at the water body, and ending at some point where the activity occurs. The alteration of the vegetation beyond the edge of the buffer means that the buffer boundary is exposed to conditions different from those in the natural forest. The edge of the buffer receives more sunlight, and is exposed to prevailing winds. From a design standpoint, then, in addition to the buffer width that is appropriate for the site conditions, buffer stability is an issue."[4]

The key here in this definition is to maintain the natural vegetation in the buffer zone. KHLT recognizes that it is possible to clear all natural vegetation up to a stream edge and then replant it with native species but working with and leaving the natural vegetation in place provides a true natural buffer and stability for the given water body. KHLT is concerned that the ACOE jurisdictional stream channel of 625 feet has now been rendered meaningless because the landowner cleared most of the trees in this zone (see Figure 5).

Forest Trails Subdivision Pedestrian Amenities

According to the Memorandum from the COH Public Works Department to the City Planner included in this meeting packet, the Department considered HCC 11.04.120 Sidewalks and non-motorized transportation corridors. The memorandum provided maps depicting connector trails to KHLT's Calvin & Coyle Woodland Park Nature Trail and the Paul Banks Elementary School Trail System which KHLT helps to maintain.

KHLT maintains the trailhead and kiosk at the end of Mariner Drive. In June 2002, KHLT granted the City of Homer a permanent sanitary sewer easement along the northern boundary of parcel # 17903056. In exchange for granting the easement, the city pledged to construct a small parking pad in the Mariner Drive right-of-way for use by visitors of Calvin & Coyle Woodland Park. The trailhead and kiosk are on KHLT property.

KHLT is pro trail and pro private property rights. KHLT wants to work with the landowner of the Forest Trails subdivision, Paul Banks Elementary School and the KPB School District, and the COH to improve trail connectivity and accessibility to schools, the greater community and continue to provide local recreational opportunities as recommended in the Homer Non-Motorized Transportation Plan. As mentioned above, KHLT is concerned about the impact this subdivision development will have on the management of the Calvin & Coyle Woodland Park and know that this development will have a direct impact on the amount of stewardship staff time and money required to meet our management obligations.

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[4] https://forestry.alaska.gov/Assets/pdfs/forestpractices/1LitBufferDesign8-7-00.pdf Web accessed on 1/31/2023.

KHLT takes great pride in our stewardship program and is careful to take into consideration all expenses related to perpetual ownership of land used and loved by the public. If future conversations propose trail connections to the KHLT property, as a nonprofit organization, KHLT will need to have the funds available to manage the increased property use.

KHLT appreciates the opportunity to comment and would be happy to answer any questions.

Sincerely,

Joel Cooper,
Stewardship Director

From: Devony Lehner
To: Renee Krause
Cc: Janette Keiser
Subject: wetlands related to proposed Forest Hills Subdivision
Date: Wednesday, February 1, 2023 3:23:09 PM
Attachments: image.png
image.png
homer wetland complexes strategies poster reduced.pdf
kenaiwatershed.org-Discharge Slope Wetlands.pdf

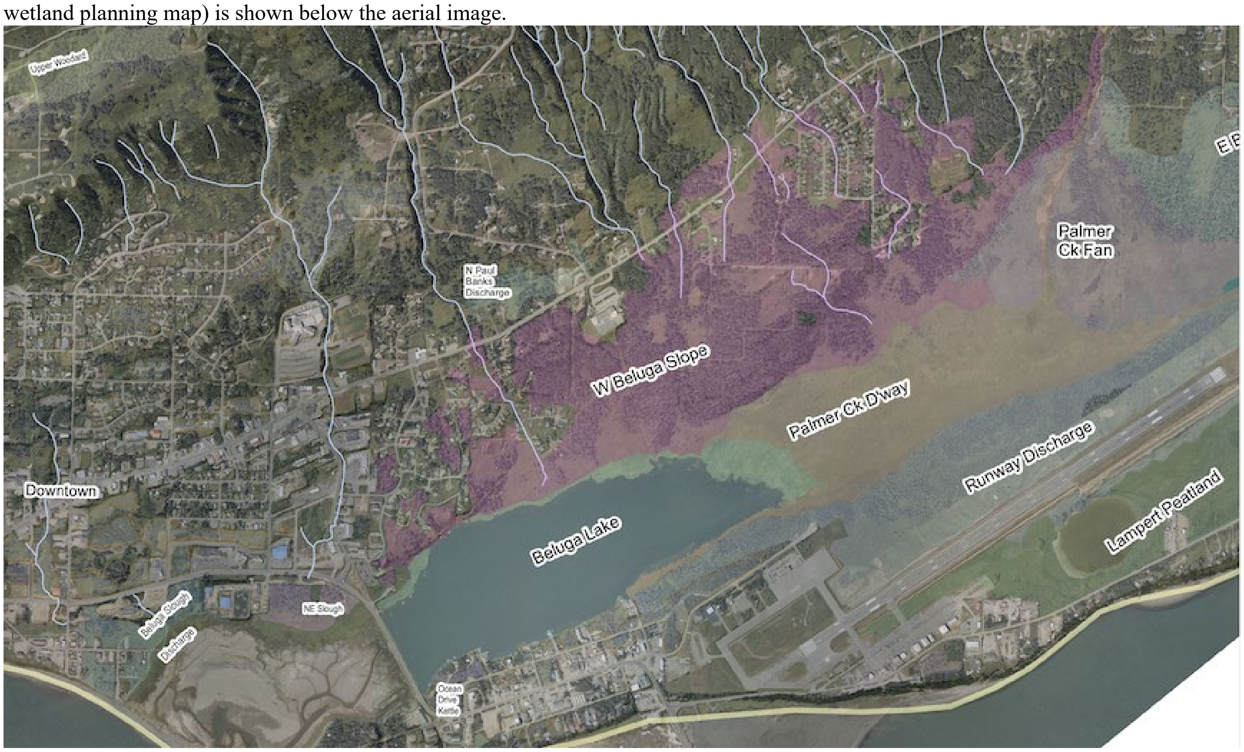
CAUTION: This email originated from outside your organization. Exercise caution when opening attachments or clicking links, especially from unknown senders.

Greetings, Renee,

I'd appreciate it greatly if a printout of this email could be a laydown at tonight's Planning Commission meeting and the email itself could be forwarded to all the Planning Commissioners. Thank you so much! I sincerely apologize that I just saw this topic on tonight's agenda.

I notice on the Planning Commission agenda for tonight (Item 9.A) that the Forest Hills Subdivision east of Paul Banks Elementary School will be discussed. I've worked on wetlands assessments and planning efforts in the Homer area for many years, and I wondered if the commissioners are familiar with the wetland planning map developed by the city when it retained wetland permitting functions. Local resident Mike Gracz, Ph.D. could inform commissioners of how this map was developed, but I thought I could at least share a copy of it for those who would be interested. The attached pdf can be enlarged as much as needed to be quite readable, and I've included a couple of screenshots from the enlarged map.

As the screenshots show, the proposed subdivision is within what is called the "West Beluga Slope" wetland area (an area of discharge slope wetlands--see attached pdf about Discharge Slope wetlands). The management recommendation for this area (as included on the wetland planning map) is shown below the aerial image.



West Beluga Slope

Public lands: Publicly owned lands should be preserved as undisturbed wetlands.
Private lands: These should be prioritized and purchased over time for inclusion in a mitigation bank whose purpose is to preserve moose habitat. Development should be discouraged. A master plan should be developed for this area as it is a very important wetland complex, and it is probably the most threatened in the City of Homer.

I can provide more information about local wetlands assessments and management, but here I'll just refer the commissioners to a couple of publications that can be downloaded from the Homer Soil and Water Conservation District publications page, these are

- Managing Kenai Peninsula Wetlands: https://www.homerswcd.org/user-files/pdfs/ManagingKPWetlands2014.pdf
- and the two volumes for the Beluga Planning Area, an area that encompasses the proposed subdivision:
    - https://www.homerswcd.org/user-files/pdfs/Beluga-Planning-Area-Homer-Vol1.pdf
    - https://www.homerswcd.org/user-files/pdfs/Beluga-Planning-Area-Homer-Vol2.pdf

I might also mention that the community "Drawdown" group during its first year focused on the value and importance of local wetlands, particularly peatlands.

Again, thank you so much, Renee!!

Devony Lehner

Homer Wetland Complexes and Management Strategies

Moose Population and Movements Around Homer

Moose have been abundant on the Kenai Peninsula for over 100 years (Lutz 1960). Moose are an important resource for hunters and are a desired spectacle for local wildlife viewers and tourists.
Densities around the state vary according to the quality of the habitat, predation levels, and other factors. The moose population around the greater Homer area (south of the Anchor River to Kachemak Bay) is currently over 500 animals and is considered a high-density population (Schwartz and Franzman 1989) with about 3 moose per square mile. This Homer moose population is currently the most abundant and productive population on the Kenai Peninsula. Moose from this population likely act as a "source" population in providing dispersing individuals to areas of lower moose densities around the lower Kenai Peninsula (Labonte et al. 1998).

Moose have evolved and adapted to habitat changes influenced by fire (Spencer and Hakala 1964, Loranger et al. 1990) and other natural disturbances. While disturbances such as fire increase the quality and quantity of browse for moose over time with the regeneration of new plant growth, the habitat changes caused by human development can remove important moose forage, eliminate access to existing forage, and/or fragment available browse into small and disconnected areas.

Moose and humans have shared the landscape in various Alaskan communities for many years. Moose inhabit areas within Anchorage because there still is available habitat. However, human-moose conflicts continue to increase as the human population grows and the amount of moose habitat decreases. Moose have been radiocollared in Anchorage using GPS technology that records locations multiple times each day. The data have not been analyzed; however, moose in urban areas appear to spend most of their time in natural areas including parks, greenbelts, and undeveloped properties near developments (R. Sinnott, Anchorage-ADF&G biologist, pers. comm.). These "green areas" provide moose browse, cover to escape from human disturbance and to stay cool, bedding areas for rest and food processing, and undisturbed areas for calving.

Moose around Homer eat a wide variety of vegetation based on the nutritional quality and availability of the plant species. In the summer when vegetation is plentiful, moose eat leaves from birch and willow along with forbs, grasses, sedges, and aquatic plants (LeResche and Davis 1973). During the winter, food is often limiting and moose focus on twigs of limited nutritional quality such as birch, willow, and ornamentals planted around human residences. Willows are an integral part of the diet for moose especially in the winter. During the winter, when moose browse greater than 30% of the previous summers growth of willow stems, there can be an increase in the production of new stems the following year (Collins 2002). However, browsing over 80% of the previous years growth will increase the production of secondary plant compounds, which limits the amount of nutrition the moose receives from the plant (Collins 2002). Continued browsing of the new annual growth of a plant, such as paper birch, year after year can eventually kill the plant (Oldemeyer 1983). Every winter in Homer, most preferred willow species suffer nearly 100% browsing of the previous summers plant growth.

Moose spend much of their time along forest edges because of the availability of good browse and for avoiding human disturbance (Bangs et al. 1985). Utilization of moose browse species will increase with the severity of the winter snowfall (Collins 2002). Winter snow conditions are often severe in Homer. Deep snow conditions cover food sources and make traveling more energetically difficult for moose, especially calves. The deep snow winters of 1991/92, 1994/95, 1997/98, and 1998/99 resulted in severe over-browsing of the available moose habitat and caused the death of over 200 moose in and around the city of Homer due to malnutrition. Even in relatively mild winters such as 2005-06, over 10 moose died in residential areas in Homer during late winter due to malnutrition. These mortality totals do not include many moose that die due to malnutrition and are unreported or undetected.

It is likely that a low-density moose population could survive within expansive human development with or without mitigating development and proactive planning for protecting moose habitat. However, mitigation measures to protect certain critical moose habitat patches in Homer will improve the long-term sustainability of our local moose population. The Homer moose population is currently a high-density population and the growth in the local moose population during the past 5-10 years has bolstered moose numbers in areas surrounding Homer. Moreover, failing to protect important habitats for moose in Homer will ensure a large proportion of the population will die due to malnutrition every winter. Negative moose-human interactions will also rise as moose increase their movements between available food patches and act defensively while feeding on small browse patches around human residences.

The purpose of identifying important areas of moose habitat and mitigating development of these habitats is not to improve or enhance the moose habitat that currently exists. The purpose is to lessen the impact of habitat loss that is inevitable with development. The assumption is that the public wants the local moose population to be healthy and negative encounters between humans and moose to be low. A desired decrease in the moose population to reduce potential human-moose conflicts should warrant a detailed plan of moose reductions via hunting rather than a slow removal of their prime habitat in the city and subsequent mortality due to malnutrition when winter snow conditions are severe. If the direction of wildlife management is to maintain a healthy moose population, then an active habitat management program is required. Providing mitigation measures for the human development of high-quality moose habitat within the City of Homer is a wise first step.

Thomas McDonough
Wildlife Biologist
Alaska Department of Fish & Game
5 June 2006

"Natural Vegetation"

Natural vegetation consists of the vegetation that would be on the site without human manipulations. Lawns are not natural vegetation. Natural vegetation retains water and filters runoff. It is important for flood control and to remove pollutants from water running off roofs, paved areas, lawns, and cleared ground.

Synopsis

In 2005-2006 representatives of the City of Homer, US Army Corps of Engineers, Environmental Protection Agency, US Fish & Wildlife Service, Kachemak Bay Research Reserve, Cook Inletkeeper, Kenai Watershed Forum, Natural Resources Conservation Service, and Alaska Department of Fish & Game met to assess Homer wetlands. After a thorough review of methods, a scoring protocol was developed and all wetlands were scored.
These strategies arose from that effort and are currently being used by some agency personnel to comment on Clean Water Act Section 404 wetland permits.

Beluga Lake

Prohibit fill in Beluga Lake or the two associated wetland polygons (docks are permitted).

Beluga Slough

Development in tidally influenced wetlands should be prohibited.

Beluga Slough Discharge Slope

Development should be encouraged in this core area of Homer. Mitigate for the loss of moose habitat. Further development north of Bunnel Avenue and east of Main Street should be discouraged. A goal of this plan is to bring private parcels in this area into conservation status. Development in tidally influenced wetlands should be prohibited.

Bridge Creek Wetlands

The wetland management strategy for this watershed is the same as the Bridge Creek Watershed Protection ordinance, which includes a prohibition on filling wetlands.

Diamond Creek Wetlands

Maintain large lot sizes. Maintain a 100 ft setback of natural vegetation along either side of Diamond Creek and its tributaries. Crossings should be perpendicular to the channel, via bridge or oversized culvert and involve the minimum amount of fill necessary for safety. Where uplands exist on a lot they must be used prior to filling wetlands. If more than 3% of wetlands on any lot are converted to hardened surface they must be compensated for with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Downtown wetlands

On City-owned parcels, maintain greenbelts incorporating storm water retention designs. Where uplands exist on a lot they must be used prior to filling wetlands. If more than 3% of wetlands on any lot are converted to hardened surface they must be compensated for with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

East Beluga Discharge

Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Site design should include hydrologic connectivity to upstream and downstream parcels. Moose habitat values are high throughout. Moose habitat should be preserved or mitigated. Development along the border with the East Homer Drainageway Complex should maintain an 85 ft buffer of natural vegetation.

East Homer Drainageway

This area should be targeted for preservation and restoration. Encourage purchasing of private lots by Kachemak Heritage Land Trust, Moose Habitat Incorporated and others. If possible, restore hydrology and repair or implement suitable storm water management measures along Kachemak Drive. Some fill may be allowed along Kachemak Drive.

Kachemak Kettle

Maintain a 100 ft buffer along the East Homer Drainageway. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Lampert Peatland

Maintain a 100 ft buffer around Lampert Lake. Mitigate for lost hydrologic, general habitat, and moose habitat functions in wetlands west of Lampert Lake. Discourage further development of wetlands east of Lampert Lake. Prohibit wetland filling more than 400 ft from Kachemak Drive.

Landfill Kettle

Restrict development to the south side of the wetlands and along the highway. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated. The peatlands should be preserved and buffered with a 50 ft setback of undisturbed natural vegetation as they are highly functional for water retention and filtering.

Loop Kettle

Loss of moose habitat should be mitigated.

NE Slough

Retain natural vegetation as is practicable. Preserve existing wetlands for water quality functions and moose habitat.

N. Paul Banks Discharge

Encourage development here. Retain natural vegetation as is practicable. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Ocean Kettle

Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Ocean Drive Kettle

Retain natural vegetation as is practicable. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Outer Loop Kettle

Retain natural vegetation as is practicable. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Overlook Park

Public lands: Maintain in conservation status and manage according to site management plan. Private Lands: Maintain moose habitat by limiting fill to the minimum necessary for a residence and minimum driveway and parking. No ditching or changes to drainageways should be allowed. Locate roads out of wetlands and out of drainageways to the extent possible. Maintain a 100 ft setback of natural vegetation on either side of Overlook Creek.

Palmer Drainageway and Fan

Maintain a 100 ft setback of natural vegetation on either side of Palmer Creek. Crossings should be perpendicular to the channel via bridge or oversized culvert and involve the minimum amount of fill necessary for safety. All of these wetlands should be preserved. A wetlands bank with Moose Habitat Incorporated will target private parcels in this area, along with the East Homer Drainageway, for purchase and preservation. Wetlands within the City of Homer that have been targeted for moose mitigation are eligible to receive credits from this bank.

Raven Kettle & Roger's Loop Depression

Avoid wetland fill. Maintain the hydrologic integrity of drainageways and water retention and filtration capacity of the complex. Where uplands exist on a lot they must be used prior to filling wetlands. If more than 3% of wetlands on any lot are converted to hardened surface they must be compensated for with swales and/ or runoff retention ponds. Loss of moose habitat should be mitigated.

Runway Discharge

Within the airport boundary wetland hydrology should be maintained. Public lands: Those tracts outside the airport boundary should be maintained and managed for the values of the Homer Airport Critical Habitat Area.
Private lands: Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

Upper Woodard

On City-owned parcels, maintain greenbelts incorporating storm water retention designs. Retain as much natural vegetation on individual lots as is practicable. Where uplands exist on a lot they must be used prior to filling wetlands. If more than 3% of wetlands on any lot are converted to hardened surface they must be compensated for with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

West Beluga Slope

Public lands: Publicly owned lands should be preserved as undisturbed wetlands.
Private lands: These should be prioritized and purchased over time for inclusion in a mitigation bank whose purpose is to preserve moose habitat. Development should be discouraged. A master plan should be developed for this area as it is a very important wetland complex, and it is probably the most threatened in the City of Homer.

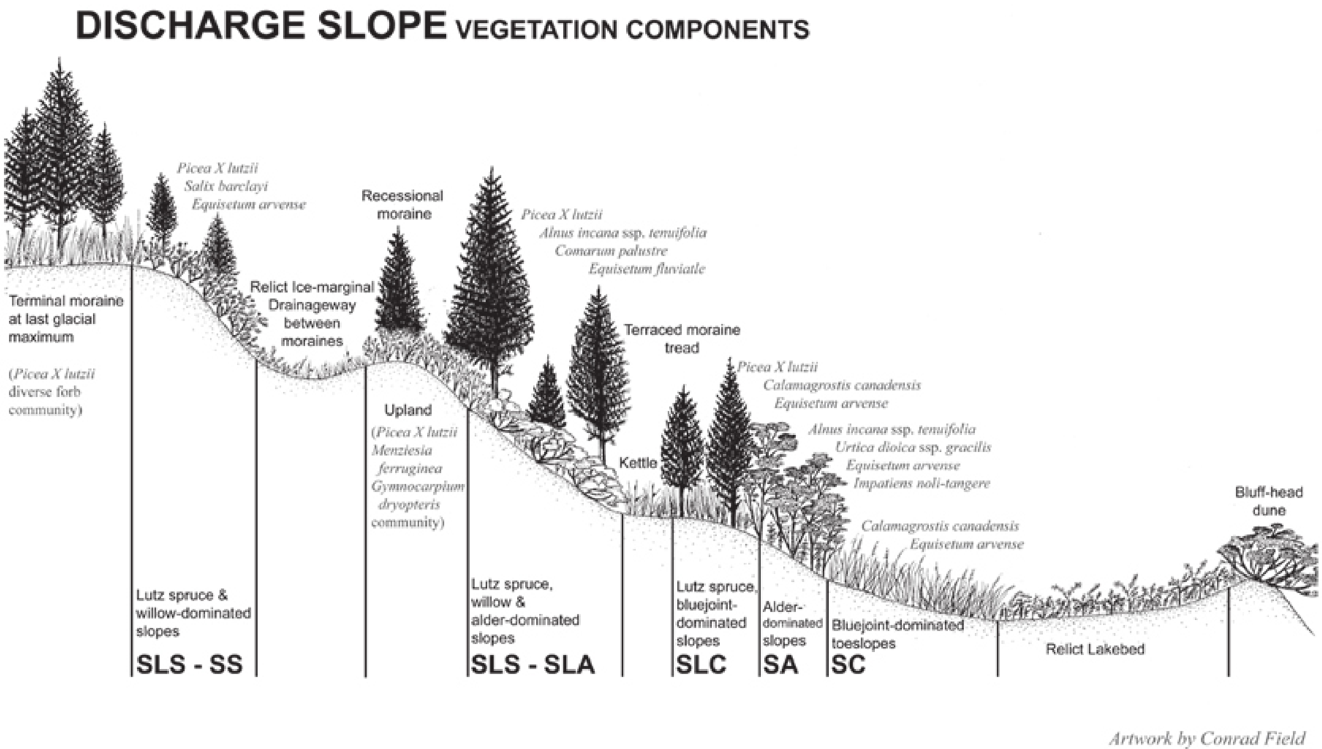
West Homer Discharge

Retain natural vegetation as is practicable. Accelerated runoff from hardened surfaces will be offset with swales and/or runoff retention ponds. Loss of moose habitat should be mitigated.

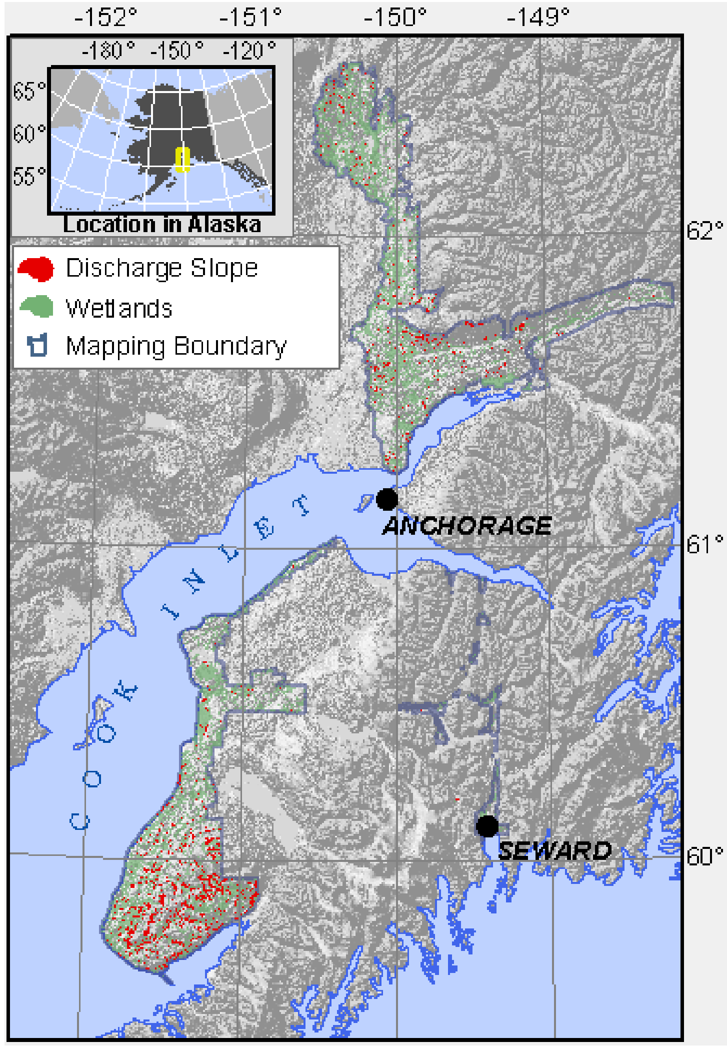
Wetlands mapped at 1:12,500, 2005.
Background imagery from Aerometric, 2003.
Prepared by Mike Gracz, Kenai Watershed Forum mike@kenaiwatershd.org
907-235-2218
4 Feruary 2011.

Discharge Slope Wetlands

kenaiwatershed.org/science-in-action/cook-inlet-wetlands/wetland-types/discharge-slope-wetlands



Mapping components of and common plants in Discharge Slope wetlands



Occurrence of Discharge Slope wetlands in the Cook Inlet Lowlands Mapping Area

Discharge Slope wetlands occur over hydric mineral soils where shallow groundwater discharges at or near the surface. Discharge Slopes typically occur at the transition between wetland and upland where the boundary can be indistinct. These wetlands often support high water tables only seasonally, and therefore can be difficult to identify. Shallow groundwater wells in the Mat-Su Valley indicate that sites with late-season water tables deeper than 150 cm can support hydric conditions sufficient to meet wetland criteria (Clark, 1995). Discharge Slopes are the most extensive geomorphic type on the Kenai Peninsula, and a Discharge Slope dominated by Lutz spruce (Picea X Lutzii) is the most common mapping component there. Especially on the southern Kenai Peninsula, extensive deposits of glacial till, which is saturated, but slowly permeable, support Discharge Slopes (see map figure, above). The unsorted till is most prevalent as terraces along the western front of the Caribou Hills physiographic subdivision of Karlstrom (1964). In other areas of the Basin these till deposits are not so extensive, and can be more permeable.

Lutz spruce with Barclay's willow and field horsetail at the margin of a small fen in the Caribou Hills.	A spruce and birch stand with a bluejoint – field horsetail understory on a kame toe slope in the Soldotna Creek watershed.

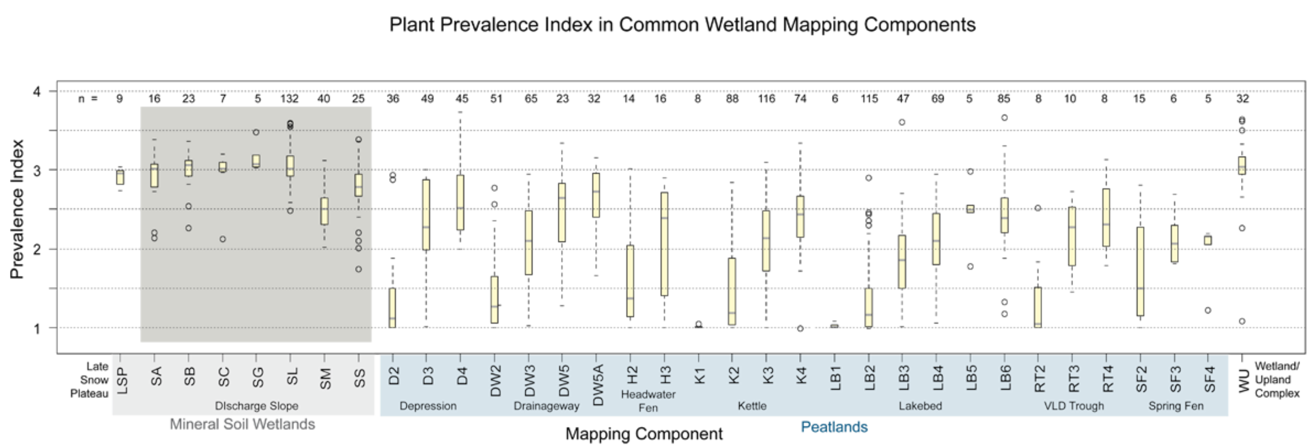
A thinleaf alder stand on a toe slope near the mouth of the Kenai River.	Lutz spruce with a rusty menziesia / field horsetail understory on a terrace riser foot slope above the large fen east of Anchor Point.

Discharge Slope components are named after dominant plant species. Broad areas at the toe-slope position of the western margin of the Caribou Hills on the Kenai Peninsula are dominated by Lutz spruce and alder and support near-surface groundwater discharge. In the area between Palmer and Houston, Discharge Slopes are frequently forested with Alaska paper birch (Betula neoalaskana) and/or white spruce (Picea glauca) with an understory of field horsetail (Equisetum arvense). Although the indicator status of paper birch (B. papyrifera) has been changed to facultative in the Cook Inlet Lowlands, it likely does not occur there. However, Alaska paper birch (B. neoalaskana), which is probably the most common species in the region, is listed as facultative upland on the 2013 list of plant indicator status, along with white spruce and Lutz spruce **(P. X lutzii)**, complicating wetland determinations on forested Discharge Slopes in the region. Further complications result because recent taxonomic changes suggest that much of the birch on the southern Kenai Peninsula is B. kenaica which has no status on the wetland plant indicator list (and therefore may be considered an upland plant). Good local knowledge, consideration of the position of the site in the surrounding landscape and augering to depth is sometimes required to accurately delineate these wetlands.

NWI and HGM

Discharge Slope wetlands are primarily classified in the US Fish and Wildlife Service National Wetlands Inventory (NWI) as forested palustrine wetlands (PFO). Forested wetlands were frequently overlooked on the NWI, which was mapped at 1:63,360. Shrub- and herbaceous-dominated Discharge Slopes are classified as PSS and PEM respectively.

The LLWW Hydogeomorphic classification of Tiner (2003) would classify most Discharge Slope wetlands as Terrene Slope groundwater-dominated Throughflow wetlands. If there is no wetland connected up slope, such as along upper terraces or stream valley walls, then they are Terrene Slope Outflow wetlands. A few have Paludified Slope wetland components, although paludification is uncommon, if present at all on the lowlands.

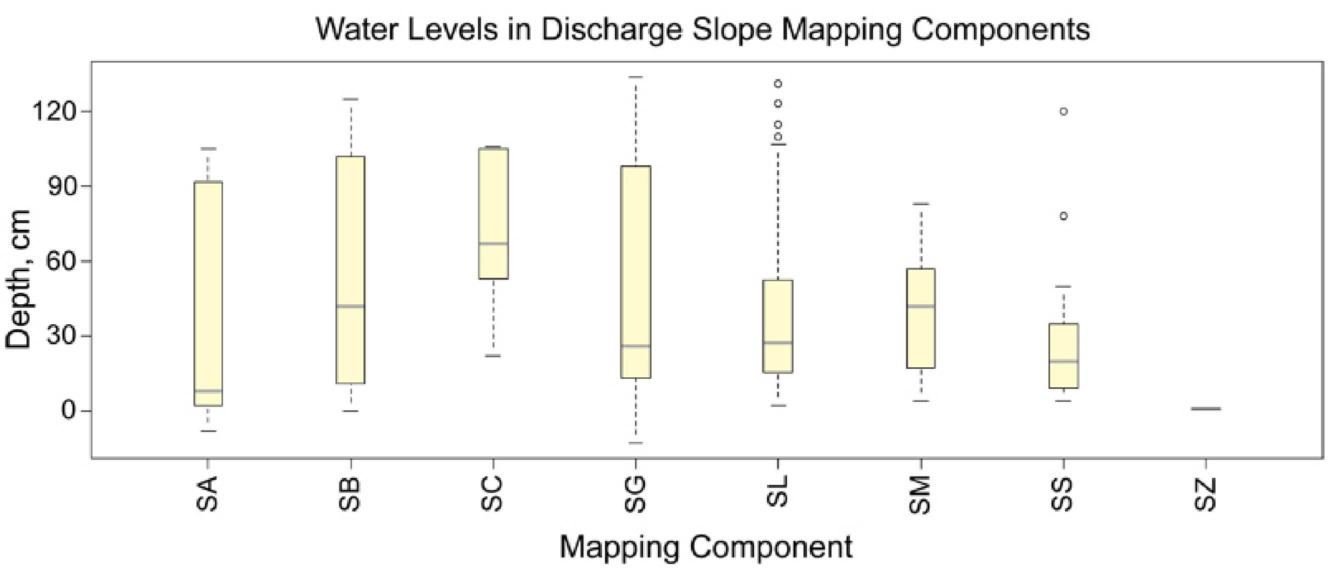


Box plots of Plant Prevalence Index (PI) in common wetland mapping components. Discharge Slope wetlands (highlighted in gray) exhibit uniformly high values for PI. Prevalence Index is calculated from the percent cover and the wetland indicator status of each plant found in a wetland plot. Lower values indicate a higher prevalence of plants assigned a wetland indicator status of obligate or facultative. Indicator status is assigned nationally, by state, and by regions within states. Prevalence

Index may be a better descriptor of the variability of the water table than one-time measurements of the actual position of the water table. Measurements are often made before the water table has had time to fully equilibrate, and are dependent on antecedent conditions. However, if Indicator Status is accurately assigned the plants present will integrate long-term average conditions.

Although Prevalence Index is a good proxy for water table position and variability in many settings, PI may be a less reliable indicator on Discharge Slopes. Lower values of PI should indicate a water table closer to the surface for a longer portion of the growing season. For example, an Index value equal to one indicates that the plot supported only wetland obligate plants (occur in wetlands greater than 99% of the time under natural conditions) and a Prevalence Index value greater than 3 suggests that the plot may not be a wetland for jurisdictional purposes. Prevalence Index may not be as reliable an indicator of water table depth and variation in Discharge Slope wetlands because the bi-modal ecological distribution of many plants can complicate assignment of indicator status. For example, bluejoint reed grass and birch may grow over well-drained soils on south-facing slopes as well as on saturated toe-slopes at the margins of peatlands.. A single value for Prevalence Index is therefore impossible to assign for some plant species. The taxonomic changes discussed above further complicate accurate assignment of indicator status within regions.

However, box plots of water level measurements made during visits to Discharge Slope wetlands generally corroborate the PI values, showing that these wetlands most often occur at the transition between wetland and upland. Median water levels in Discharge Slope mapping components are often near 30 cm below the surface, the wetland cut-off.



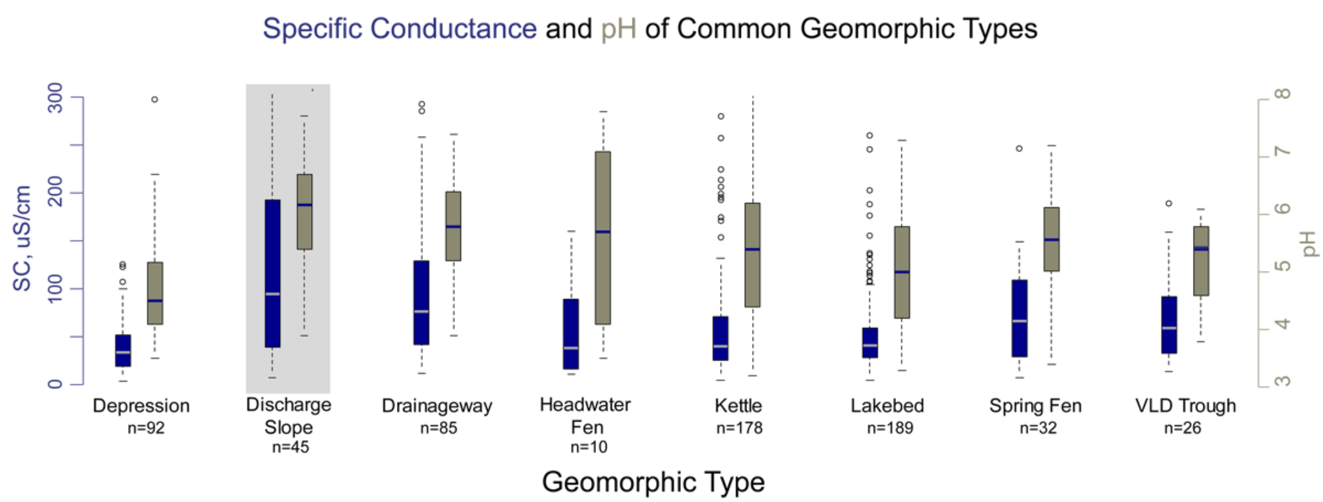
A= alder (n=10), B= birch (n=18), C= bluejoint reed grass (Calamagrostis canadensis) (n=5), G= White spruce (Picea glauca) (n=5), L= Lutz spruce (Picea x lutzii) (n=108), M= black spruce (Picea mariana) (n=26), S = willow (Salix spp.) (n=15), Z = a single high elevation meadow on the upper slopes of Baldy Ridge, above Wasilla in the Matanuska Valley.

Note however, that some deviations are apparent. Compare the PI values to depth at black spruce Discharge Slopes (SM), for example. PI is low, but water level measurements are relatively deep. Alder Discharge Slopes (SA) have a shallow median water level, yet median PI is near 3.

Because of these problems with water level variation at the wetland/upland transition, other factors such as slope, aspect, and elevation are more important in driving differences among Discharge Slope wetlands. By contrast, water level variability is very important in peatlands (highlighted in blue in the first graph). Because water level variation is less important in Discharge Slope wetlands, plant species dominance was chosen in place of a hydrologic component to distinguish mapping components. Within the hydrogeomorphic setting of discharge slopes, plant species probably best reflect unique combinations of environmental conditions in different wetlands.

In the box plots, yellow boxes enclose the first through third quartile (where 50% of the data values lie); the gray bar is the median, and the whiskers extend to the last value within 1.5 times the inner quartile range. Values lying beyond 1.5 times the inner quartile range are plotted as hollow circles. The number of samples for each map component is given across the top.

Box plots of specific conductance (SC- blue) and pH (brown) in the common geomorphic types. A few values for specific conductance greater than 300 micro-Siemens/cm are not shown. Discharge Slope wetlands (highlighted in gray) have the highest median values for both pH and specific conductance when compared to wetlands in other common geomorphic settings in Cook Inlet Basin. The high values indicate that that groundwater connections to the surface are relatively strong.



In box plots, the boxes enclose the first through third quartile (where 50% of the data values lie); the horizontal bar in the box is the median value, and the whiskers extend to the last value within 1.5 times the inner quartile range. Values lying beyond 1.5 times the inner quartile range are plotted as hollow circles.

Wetland Indicators

Table 1. Wetland Indicators in Discharge Slope map components throughout the Cook Inlet Lowlands.

Map Component	Peat Depth (cm)	Water Table (cm)	Redox features (cm)	Saturation (cm)	pH	Alkalinity mg/l as CaCO3	Specific Conductance µS/cm	Plant Prevalence Index
SA	**90** (16)	**26** (15)	**23** (6)	**3** (7)	**6.2** (8)	**39.0** (3)	**177** (5)	**2.92** (16)

SB	**82** (19)	**54** (19)	**29** (15)	**42** (18)	**6.5** (10)	**61.6** (2)	**182** (9)	**2.99** (23)
SC	**57** (7)	**71** (5)	**24** (6)		**7.0** (1)			**2.93** (7)
SG	**20** (5)	**52** (5)	**14** (4)	**47** (4)	**5.7** (4)	**3.0** (1)	**75** (4)	**3.16** (5)
SL	**31** (128)	**38** (108)	**26** (82)		**5.4** (9)	**4.8** (4)	**49** (2)	**3.05** (132)
SM	**46** (40)	**37** (32)	**34** (15)	**28** (24)	**5.4** (12)	**0.0** (4)	**62** (10)	**2.49** (40)
SS	**43** (22)	**27** (18)	**28** (9)	**9** (3)	**6.7** (5)	**84.3** (4)	**259** (5)	**2.72** (25)
SZ	**23** (1)	**1** (1)		**1** (1)	**6.0**(1)		**18.4** (1)	**2.35** (1)

Explanation:

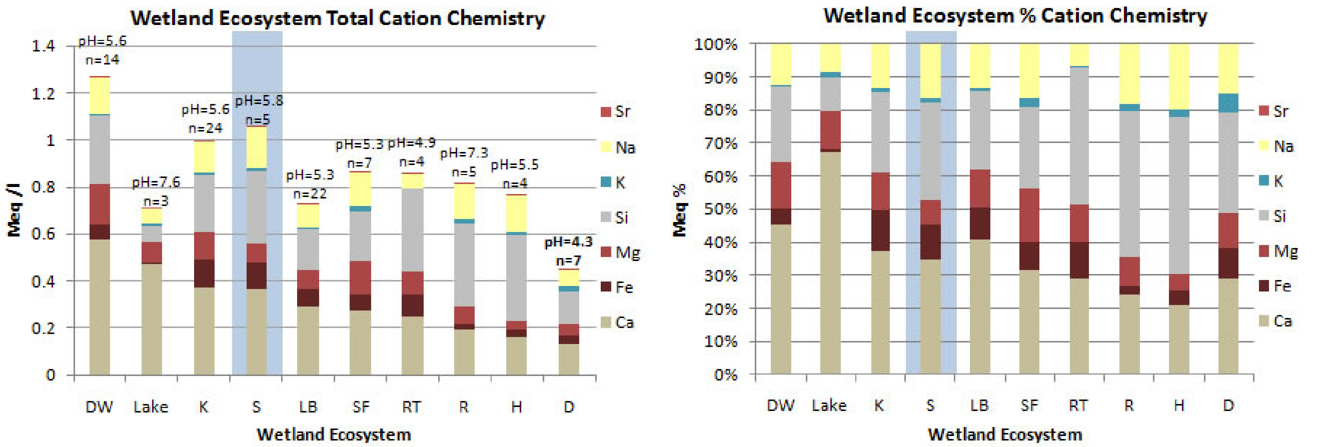
- Numbers in parentheses indicate number of samples.
- Peat depth is a minimum, because some sites had thicker peat deposits than the length of the auger used (between 160 – 493 cm).
- Water table depth is a one time measurement. At sites with seasonally variable water tables this measurement reflects both the conditions that year, and the time of year.
- Redox features with deep depths typically indicate deeper peat deposits, which mask redox indicators so the depth corresponds to the peat thickness.
- pH and specific conductance measured in surface water or a shallow pit with a YSI 63 meter calibrated each sample.
- Plant Prevalence Index calculated based on Alaska indicator status downloaded from the USDA PLANTS database, which may use different values than the 1988 list.

Soils and Plant Communities

Table 2. Common soils and plant communities found in Discharge Slope wetlands.		
Map Component	**COMMON SOILS**	**COMMON PLANT COMMUNITIES**
SA	Typic Cryorthents BELUGA	Alnus viridis ssp. sinuata / Equisetum arvense Alnus viridis ssp. sinuata / Equisetum palustre Alnus incana ssp. tenuifolia / Calamagrostis Paper birch – White spruce / Thinleaf alder

SB	TYPIC CRYAQUENTS ESTELLE KICHATNA	Paper birch – White spruce / Thinleaf alder Paper birch – Black spruce / Thinleaf alder
SC	BELUGA Typic Cryorthents	Calamagrostis canadensis – Equisetum arvense
SG	STARICHKOF HISTOSOLS CRYAQUEPTS SOLDOTNA	Paper birch – White spruce / Thinleaf alder Picea x lutzii / Salix barclayi / Calamagrostis canadensis
SL	STARICHKOF KILLEY DOROSHIN MUTNALA	Picea x lutzii / Salix barclayi / Calamagrostis canadensis Picea x lutzii / Equisetum arvense – Calamagrostis canadensis Picea x lutzii / Menziesia ferruginea / Equisetum arvense
SM	HISTOSOLS CRYAQUEPTS STARICHKOF	Picea mariana / Equisetum sylvaticum – Ledum palustre ssp. decumbens Picea mariana / Equisetum arvense – Betula nana
SS	KILLEY STARICHKOF DOROSHIN	Salix barclayi / Rich Salix barclayi / Calamagrostis canadensis – Equisetum arvense Picea x lutzii / Salix barclayi / Calamagrostis canadensis
SZ	CRYAQUEPTS	UNDEFINED
HISTOSOLS are any organic soils greater than 40 cm deep.		

Cation Chemistry



Cation chemistry by Geomorphic Component. Discharge Slope wetlands (highlighted in blue) have high cation concentrations compared to other Geomorphic Components. This indicates the strong groundwater discharge influence on porewater chemistry. Although calcium and silicon show the greatest concentrations, magnesium and iron concentrations in our area are high for natural waters. DW = Drainageway, K = Kettle; S = Discharge Slope; LB = Lakebed; SF = Spring Fen; RT = VLD Trough; R= Riparian; H = Headwater Fen; D = Depression.

Samples were collected from a surface pool where possible, otherwise from a separate shallow pit excavated to just below the water table. All samples were filtered through either a 0.2 micron filter using a disposable syringe, or pumped through a 0.45 micron filter using a peristaltic pump. Samples were acidified with ultra-pure nitric acid and kept cool until analysis on a direct current plasma spectrometer to about 5% accuracy (except K, 10-20% accuracy).

Discharge Slope Vegetation Components:

Map unit names are made of combinations of map components. A suffix ‘c’ indicates a created wetland, and a ‘d’ indicates a highly disturbed wetland.

SA: Dominated by alder, usually Alnus incana ssp. tenuifolia

- **NWI:** PSS1Bn,g
- **HGM**: Terrene Slope groundwater-dominated Throughflow

SB: Dominated by birch. Taxonomy of local birches is problematic; tree birches in this project have been designated Betula payrifera, realizing that B. Kenaica is widespread, and other taxa are probably present.

- **NWI:** PFO1Bn,g
- **HGM:** Terrene Slope Outflow

SC: Dominated by bluejoint reed grass (Calamagrostis canadensis).

- **NWI:** PEM1Bn,g
- **HGM**: Terrene Slope groundwater-dominated Throughflow

SG: Dominated by white spruce (Picea glauca); occurs primarily in the Matanuska Susitna Valley. Much of the spruce that is not black spruce (P. mariana) is Lutz spruce (Picea X Lutzii), a hybrid between the more continental white spruce and coastal Sitka spruce (P. sitchensis).

- **NWI:** PFO4Bn
- **HGM:** Terrene Slope Outflow

SL: Dominated by Lutz spruce (Picea X Lutzii), a hybrid between the more continental white spruce (P. glauca) and coastal Sitka spruce (P. sitchensis). Most common on the Kenai Peninsula, especially closer to maritime influence.

- **NWI**: PFO4,5Bn
- **HGM:** Terrene Slope Outflow, if adjacent to upland.

If wetlands above and below: groundwater-dominated Throughflow.

SM: Dominated by black spruce (Picea mariana).

- **NWI**: PFO4Bn,g
- **HGM**: Terrene Slope Outflow

SP: Dominated by Sitka spruce (Picea sitchensis), two wetland polygons in Seward.

- **NWI:** PFO4Bn
- **HGM:** Terrene Slope Outflow

SS: Dominated by willow, usually Barclay willow (Salix barclayi).

- **NWI:** PSS1Bn
- **HGM:** Terrene Slope groundwater-dominated Throughflow,

if wetlands above and below. If wetlands only below, then: Terrene Slope Outflow.

SZ: High elevation mountain meadows of various lush forb assemblages. Mapped only along the upper slopes on Baldy Ridge, above Wasilla.

- **NWI**: PEM1Bn
- **HGM:** Terrene Slope groundwater-dominated Throughflow

Table 3.Summary of and Cook Inlet Discharge Slope Map Unit occurrence.

Map Unit	N	Hectares	% Polygons	% Area
SA	70	288	0.25	0.15
SAB	1	0.3	0.00	0.00
SAC	20	167	0.08	0.09
SAG	3	12	0.01	0.01

SAL	50	604	0.21	0.32
SAM	3	20	0.01	0.01
SAS	9	50	0.04	0.03
SB	90	991	0.37	0.53
SBA	4	19	0.02	0.01
SBd	3	7	0.01	0.00
SBG	7	14	0.03	0.01
SBM	10	295	0.04	0.16
SC	38	206	0.16	0.11
SCA	20	114	0.08	0.06
SCAd	5	9	0.02	0.00
SCd	3	0.6	0.01	0.00
SCG	2	2.7	0.01	0.00
SCL	10	63	0.04	0.03
SCLd	7	7.9	0.03	0.00
SCS	20	107	0.08	0.06
SCSd	1	24	0.00	0.01
SG	59	861	0.25	0.46
SGA	4	84	0.02	0.04
SGB	19	123	0.08	0.05
SGC	3	69	0.01	0.04
SGM	9	105	0.04	0.05
SGS	4	15	0.02	0.01
SL	1463	18,715	6.08	9.97
SLA	66	635	0.27	0.34
SLC	7	49	0.03	0.03
SLCd	2	2.1	0.01	0.00
SLd	6	37	0.02	0.02
SLM	58	447	0.24	0.24

SLMd	2	2.9	0.01	0.00
SLS	336	3164	3.18	2.53
SLSd	1	0.7	0.00	0.00
SM	765	4851	3.18	2.53
SMA	5	34	0.02	0.02
SMB	31	200	0.13	0.11
SMC	1	1.7	0.00	0.00
SMd	7	29	0.03	0.02
SMG	24	121	0.10	0.06
SML	42	340	0.17	0.18
SMLd	1	5.9	0.00	0.00
SMS	9	55	0.04	0.03
SPS	2	6.7	0.01	0.00
SS	315	1580	1.31	0.00
SSA	17	109	0.07	0.06
SSC	29	176	0.12	0.09
SSG	3	15	0.01	0.01
SSL	272	2149	1.13	1.14
SSM	13	63	0.05	0.03
SZ	20	214	0.08	0.11

diversity

MDPI

Review

Riparian Buffers as a Critical Landscape Feature: Insights for Riverscape Conservation and Policy Renovations

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Abstract: Riparian zones are critical for functional integrity of riverscapes and conservation of riverscape biodiversity. The synergism of intermediate flood-induced disturbances, moist microclimates, constant nutrient influx, high productivity, and resource heterogeneity make riparian zones disproportionately rich in biodiversity. Riparian vegetation intercepts surface-runoff, filters pollutants, and supplies woody debris as well as coarse particulate organic matter (e.g., leaf litter) to the stream channel. Riparian zones provide critical habitat and climatic refugia for wildlife. Numerous conservation applications have been implemented for riparian-buffer conservation. Although fixed-width buffers have been widely applied as a conservation measure, the effectiveness of these fixed buffer widths is debatable. As an alternative to fixed-width buffers, we suggest adoption of variable buffer widths, which include multiple tiers that vary in habitat structure and ecological function, with each tier subjected to variable management interventions and land-use restrictions. The riparian-buffer design we proposed can be delineated throughout the watershed, harmonizes with the riverscape concept, thus, a prudent approach to preserve biodiversity and ecosystem functions at variable spatial extents. We posit remodeling existing conservation policies to include riparian buffers into a broader conservation framework as a keystone structure of the riverscape. Watershed-scale riparian conservation is compatible with landscape-scale conservation of fluvial systems, freshwater protected-area networks, and aligns with enhancing environmental resilience to global change. Sustainable multiple-use strategies can be retrofitted into watershed-scale buffer reservations and may harmonize socio-economic goals with those of biodiversity conservation.

Keywords: riparian zones; riparian buffers; streams; rivers; riverscapes; watersheds; catchments; conservation

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1. Introduction

Riparian zones are influenced by hydrodynamic forces in fluvial ecosystems (i.e., lotic systems, such as rivers and streams) and represent transitional aquatic-terrestrial interphase bordering these ecosystems, and as such have numerous functions. They connect terrestrial and aquatic habitats through surface runoff, subsurface flow, and flooding [1–3]. Riparian zones are characterized by saturated soils, elevated water tables, and a three-dimensional configuration, which extends laterally into the river basin, vertically into the riparian canopy and groundwater, and longitudinally along fluvial channels [1–4]. Through surface and subsurface hydrologic processes, riparian buffers colligate waterbodies with adjacent uplands and govern the exchange of energy and matter between aquatic and terrestrial ecosystems [3,5]. The three-dimensional configuration, mediation of energy and matter flow, habitat heterogeneity, and the unique biotic communities make riparian zones an integral constituent of riverscapes [6,7]. The constituents and conceptual framework of riverscapes vary considerably among various disciplines of applied and foundational ecology. Lotic systems and their biota, including the spatiotemporal dynamics (e.g., species-habitat and community-scale interactions) inherent to these systems, nested within socioecological landscapes are collectively referred to as a riverscape [8,9]. While accommodating this broader viewpoint, riverscapes can be defined as spatially structured, hierarchically organized, heterogeneous habitat mosaics nested within the river continuum [10–14].

Natural disturbances in riparian systems enhance environmental complexity both spatially and temporally [3,15]. Through variable flow regimes, alternative erosion-deposition patterns, and channel migration, fluvial processes have sculpted riparian zones into landform mosaics with modified geomorphology and edaphic conditions [1,3]. Riparian vegetation is substantially structured by the hydrologic gradient (i.e., the variability in the duration, frequency, and timing of inundation). Interspecific differences in flood tolerance and moisture dependence produce spatial and temporal patterns in the riparian community composition and cover types along the hydrologic gradient [16]. Riparian zones have a disproportionate influence on the local ecosystem, yielding a multitude of ecosystem services, thus considered a keystone resource within the landscape [3,4,17].

Studies that have spanned across numerous global ecoregions have emphasized critical and complex functions of riparian zones, including regulation of aquatic thermal properties [3,4]; bank stabilization [1,17]; nutrient assimilation, silt and sediment retention [18,19]; groundwater recharge [3]; and input of woody debris and other allochthonous matter [1,15].

Given these complex ecosystem services and functions and extensive habitat degradation experienced by lotic systems, the scientific community has widely recognized the need for riparian zone conservation. Numerous natural-resource management and conservation authorities have implemented regulatory policies and established guidelines targeting riparian-buffer delineation. The biological effectiveness of existing policies is debatable, while such regulatory enforcement has received substantial criticism [20,21]. Existing policy standards in certain jurisdictions can be outdated, resulting in conflicts with the current scientific comprehension of riparian ecology. Originally intended to mitigate non-point source pollution, riparian buffers can be managed for wildlife conservation as well as to boost ecosystem functions [22,23]. Although the ecological role of riparian zones has been long recognized, scientific literature on riparian buffers mostly focuses on either a single taxon (e.g., fish, amphibians) or a handful of ecosystem functions (e.g., nutrient filtering, pollution remediation). We argue that a review of current literature on riparian systems will lay a foundation for a multi-taxa multi-functional focus on riparian-zone conservation, painting a holistic ecological framework to reinforce policies and regulatory actions. Many studies on riparian-buffer management are shoehorned towards specific localities or geographic regions. Thus, an overview of such region-specific approaches and their applicability across broader geographic contexts are both prudent and timely needs. In this review, specifically targeting temperate North American riparian systems, we intend to (i) explore their overall ecological benefits; (ii) discuss threats and conservation challenges; and (iii) synthesize conservation actions and policy reforms targeting riparian conservation. Our review will help conceptualize conservation potential and ecological values of riparian buffers and thereby provide a foundation to formulate novel conservation approaches to protect and manage riparian zones.

2. Riparian Buffers—A Nexus for Biodiversity

Riparian habitats represent a nexus of biodiversity where both species richness and density of wildlife are disproportionately high compared to nearby terrestrial habitats [1,24]. Many semi-aquatic and aquatic organisms, particularly those with complex life histories (e.g., amphibians), depend on riparian zones for a significant portion of their lifecycles [25–27]. Riparian zones in the United States account for <5% of the land area (15–50 million hectares) yet provide habitat for over 70% of vertebrate species and are thus considered a keystone habitat [28]. In the arid southwestern United States, riparian habitats account for <1% of the landscape yet are enriched with 80–90% of regional wildlife diversity [29]. Riparian zones exhibit high levels of species richness and diversity and provide habitats for numerous habitat specialists. Riparian systems can act as local refugia for species, thus serving as population sources to support recolonization of disturbed habitats, such as commercial timberlands [30,31]. Bats and birds use forested riparian corridors as flyways, foraging grounds, and roosting sites [32,33]. During the migratory season, the avifaunal richness of riparian zones is at least an order of magnitude higher than the nearby uplands due to increased foraging opportunities and overwintering sites [34]. Amphibian dependency on riparian buffers is pronounced in the Pacific Northwest of the United States, where 47 species are either obligate or facultative stream associates [35]. Many turtles are particularly dependent upon riparian buffers for dispersal, foraging, hibernation, and oviposition. Floral biodiversity, particularly bryophytes, pteridophytes, and herbaceous plants, is remarkably high in riparian buffers [36]. In northern hardwood forests, native vascular plant richness in riparian forests was remarkably higher compared to upland, interior forests, while invasive and ruderal species were less frequent in the former [37]. Marked floristic species turnover rate (beta diversity) between riparian buffers and adjacent uplands heightens species complementarity along the aquatic-upland gradient, which also generates a greater landscape-scale species richness (gamma diversity) [15].

3. Riparian Zones—Ecological Functions

3.1. Reciprocal Energy and Matter Subsidies

Riparian zones, particularly those with mature forests, supply copious amounts of organic matter and allochthonous input to fuel food-web dynamics in lotic systems (Figure 1). Forests provide an abundant supply of woody debris into rivers, which trap sediments, fine and coarse particulate organic matter, and silt, forming habitats and microsites for aquatic macroinvertebrates and fish [38,39]. Coarse particulate organic matter and fine particulate organic matter are the nutrient sources for detritivores and shredders, which in turn become profitable foraging resources for predatory vertebrates [40,41]. Through decomposition, microbial biofilms growth on woody debris yields dissolved and suspended organic matter [42], which is critical for buffering pH and sequestrating heavy metals [17].

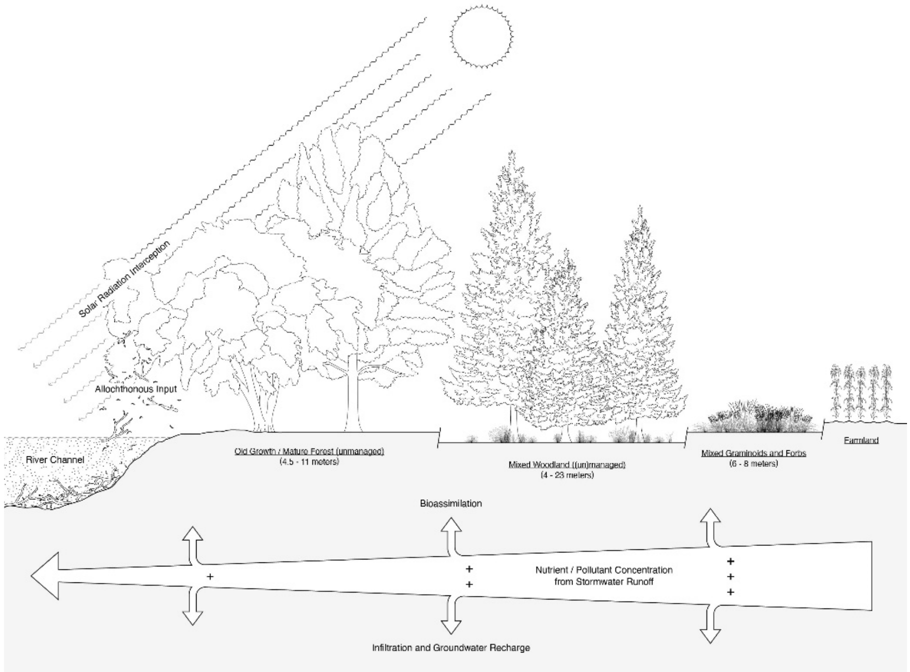

Figure 1. Ecological structure, functions, and multi-tiered delineation of riparian buffers.

Often overlooked or undervalued, the biphasic life histories of many organisms drive aquatic-upland reciprocal energy and nutrient subsidies, highlighting an inextricable connection of the riparian zone to the river itself [43]. Shifting trophic dynamics from allochthonous to autochthonous production and replacement of specialist feeding guilds (i.e., insectivores, predators) with generalist grazers has been documented after riparian zones have been harvested or otherwise degraded [44–46]. The ultimate consequences of such trophic shifts will likely lead to biotic homogenization where the species turnover and functional diversity of aquatic biodiversity from headwaters to lower reaches attenuate along the river continuum [47].

3.2. Critical Habitat, Channel Stabilization, and Nonpoint-Source Pollution Mitigation

Riparian vegetation supplies particulate organic matter in the form of leaf litter and woody debris of variable sizes and decay classes that structure geomorphology and habitat complexity of the aquatic core-forming microsites and refugia for aquatic fauna [17,40,41]. Woody debris resists erosive water currents and redistributes the flow throughout the riverbed resulting in mosaic patterns of erosion and alluvial depositions along river corridors, which further contribute to habitat heterogeneity [3,23]. Deep-water pools formed by debris dams provide critical habitats for spawning and refugia during low-flow seasons [48]. Further, the abundance of large within-stream woody debris is positively associated with turtle density, as it provides critical thermoregulatory sites [49,50].

By intercepting precipitation and slowing surface runoff, riparian buffers filter silt and sediments, heavy metals, agrochemicals, organic wastes, and pathogens, thereby preventing these contaminants from reaching the aquatic core or groundwater [17,19,39,51]. These buffering functions become crucial in urban and agricultural landscapes where nonpoint-source pollution via surface runoff intensifies during rainstorms [51,52]. The root masses of riparian vegetation assist in maintaining the physical structure of soil and reducing soil erosion [17,39]. Decelerated surface runoff enhances groundwater recharge through the riparian soils, even during storm surges [17,53]. Water quality metrics of buffered aquatic systems are more stable than unbuffered systems. For instance, enhanced siltation elevated peak discharge velocities, and channel incision was reported in unbuffered rivers. In contrast, buffered rivers contained the highest volumes of riverbed woody debris, lower sand/slit content, and reduced river discharge, as well as lowered fecal coliform and nutrient concentrations [54,55].

Riparian buffers intercept sedimentation and prevent the loss of interstitial spaces of stream beds, which represent critical habitat for aquatic organisms [31,53,56]. Buffered streams support a diverse aquatic macroinvertebrate community, including environmentally sensitive taxa [54]. In contrast, freshwater turtles inhabiting streams without adequate riparian buffering, particularly those dissecting urban landscapes, exhibit skewed sex ratios and age structures, reduced juvenile recruitment, heightened incidental mortality, and subsidized predation [56,57].

3.3. Climate Change Resistance and Resilience

Riparian zones are both spatially and temporally dynamic and stochastic; as such, riparian biota has evolved life-history strategies and adaptations under environmental variations, which may make them either more resilient or resistant to climate change [5]. Riparian vegetation exhibits a wide array of adaptive morphological and physiological traits—heterophylly (production of variable leaf forms in response to environmental conditions), heteroblasty (abrupt morphological changes in the ontogenetic development), variable-depth root systems, propagule dormancy, and persistence under variable disturbances (flooding, fluvial, fire) and soil conditions (increased salinity)—that confer resilience to extreme climates [5]. Riparian buffers create spatial connectivity across lateral, longitudinal, and vertical dimensions, which provides multiple pathways for species migrations in response to climate shifts [3,58,59]. Additionally, riparian buffers form climate envelopes with high humidity and thermal stability that function as climate refugia [42]. For instance, large trees typical of intact riparian zones create a continuous canopy, which intercepts solar radiation and regulates stream thermal properties [55]. Indeed, harvesting riverbank vegetation has often resulted in elevated average and maximum water temperatures, increased diel fluctuations and incidences of thermal extremes, and erratic disruptions in seasonal thermal regimens [55,60].

4. Threats and Conservation Challenges

Streams and rivers are among the most imperiled habitats in the United States, as well as across the world [58,59,61]. The current estimates for the riparian-zone surface area of the United States range from 15–50 million hectares, of which >90% are degraded [29,62]. There is growing anthropogenic pressure on riverine ecosystems. In the conterminous United States, a significant proportion of the population dwells within 1-km of a river. Nevertheless, only 2% of stream reaches receive riparian protection [62]. Riparian protection remains uneven across the United States. For instance, compared to eastern North America or the Great Plains, riparian zones of the western United States receive enhanced protection where federal land stewardship ensures appreciable conservation attention. Nationwide, ~480,000 km of rivers exhibit degraded water quality, with impaired riparian buffering being at least partly responsible. Impaired riparian systems experience increased solar incidence, dry microclimatic conditions, and lack of environmental complexity, making them unfit for native wildlife, with the exception of a handful of urban exploiters, urban-adapted human commensals, and invasive species [63].

4.1. Anthropogenic Land-Cover Changes and River Modifications

As ecosystem functions of riparian zones rely heavily on fluvial processes, anthropocentric alterations fundamentally influence riparian dynamics [36]. To facilitate navigation, irrigation, and mitigate threats of catastrophic flooding, rivers have undergone drastic modifications with channelization, diversion, and impoundment, which impacts the riparian zone [36,64,65]. In the United States, there are over 2 million dams that influence nearly 90% of regional drainage basins, disrupting both longitudinal and lateral connectivity [66]. For example, permanent upstream floodplain inundation, downstream sediment and nutrient deprivation, damped hydrologic variability, and downstream peak flow attenuation lead to major modifications in the riparian structure and function [29,63]. Dams also impede downstream hydrochory and plant propagule recruitment, which subsequently suppresses riparian vegetation [67,68].

Channelization and bank-stabilization structures sever the connection between the riparian zone and the in-stream habitats, which prevents recruitment of riparian vegetation, disrupts the riparian microhabitat structure, lowers the riparian water table reduces the frequency of overbank flow, and homogenizes shoreline complexity [29,34]. Channelized river corridors lack soft sandy riverbed substrates, sandbars, and large downed wood, which are critical for basking and nesting turtles [64]. Cumulative effects of flow regulation, drainage, and floodplain reclamations transform anastomosing, meandering, and braiding rivers into oversimplified single-tread channels that are severed from riparian zones [65].

Loss of riparian forest cover is particularly notable in anthropogenic landscapes. Biotic homogenization—reduced species turnover across environmental gradients—as a consequence of urbanization was observed across American riverscapes [69,70]. Declining riparian forest cover changes aquatic productivity, such as the prolific growth of exotic species and filamentous algae at the expense of unicellular phytoplankton and non-vascular plants [47,61]. The proliferation of these primary producers neither contributes to food webs nor is exploited by consumers [42,71]. Sporadic changes in seasonal river temperatures resulting from loss of streamside vegetation can negatively impact juvenile development among fish and trigger adverse behaviors, such as untimely migration and phenological mismatches [23,42].

4.2. Recreation-Based Degradation

Given unique aesthetic and scenic values, recreation-based development and activities (whitewater rafting, canoeing, swimming) are often concentrated within riparian zones [72,73]. Proximity to large rivers is among the most demanding landscape features sought by recreational developers as well as amenity migrants for secondary and vacation homes [74,75]. Snag removal and vegetation clearance in the riparian zone to boost recreational and scenic values led to declining diversity among turtles in the northern Midwest [38]. Increased cover of invasive and weedy species is frequently observed in riparian zones impacted by human disturbances [34]. For instance, invasive plant species were found to be absent from river reaches where the surrounding land use was largely undisturbed and exhibited greater complexity in vegetation structure, suggesting that these reaches were more resistant to invasion than reaches, which have experienced degradation [76]. Deliberate introduction of exotic species as landscape ornaments is partly responsible for such biological invasions, at least in the early phases of establishment outside the native range. Riparian corridors are conduits for plant propagules, therefore, riparian zones are particularly vulnerable to plant invasions. Recreational activities enhance the human footprints in riparian zones (e.g., vegetation removal, changes in natural land-cover, simplification of the structural complexity) as well as the fluvial channel (e.g., modifications in the riverbed and bank geomorphology), which can further exacerbate biological invasions [76].

4.3. Resource Overuse

Land development in the riparian zones and floodplains increases the acreage of impervious surfaces, which alter local hydrodynamics and fluvial processes. Riparian forests are high in aboveground biomass, making them particularly susceptible for commercial timber harvesting [1]. Logging or clearcutting within the buffer zone can lead to localized extirpation of riparian specialists [36,48]. Additionally, the paper, pulp, and biofuel industries are also attributed to intensified silvicultural practices within the United States. River corridors have been historically used as effective conveyers of harvested timber. However, to facilitate convenient access to river channels to transport timber to sawmills downstream, riparian vegetation and within-stream wood are often removed [77]. River valleys historically were and continue to be targeted by mineral harvesters, particularly for gold mining, resulting in the clearcutting of riparian vegetation as well as the excavation of streambed substrates [59,73]. Indeed, ecosystems within the riparian zone have been and continue to be set on courses exceeding their historical norms due to anthropogenic influences relating to resource overuse [78].

4.4. Agriculture and Farming

Due to high productivity and soil fertility, riparian habitats across the United States have been converted to row-crop farms nationwide [34]. Moreover, nutrient-rich soils of the riparian zones of large, sluggish rivers and dependable access to water have led to the transformation of such riparian zones into extensive croplands [73]. Given high productivity and access to water and shade, riparian zones attract livestock, which results in overgrazing of riparian vegetation and soil compaction. Setting aside forested buffers for conservation is economically costly, thus farming operations usually encroach the riparian zone, resulting in the conversion of diverse native riparian flora into monocrop stands.

4.5. Challenges in Riparian Conservation

Much of America's riparian zones are located within privately owned lands. Unfortunately, many of these landowners prioritize profit over sustainability [39,73]. Streams and rivers crossing private lands, especially low-order reaches, receive little to no legislative protection [79]. Land managers of local jurisdictions are often underinformed about riparian functions and biodiversity, hence policies emerging from local authorities are unlikely to generate tangible conservation benefits [52]. Taking riparian lands out of production and re-vegetating buffers are prohibitively expensive, thus, regulations on riparian zones are often resisted by farmers [52,80]. Consequently, riparian conservation policies in the United States are often distilled into politically palatable decisions driven by what private landowners are willing to concede [17].

5. Conservation Efforts

Maintaining intact riparian zones has long been recognized as a crucial element in biodiversity conservation. During the last few decades, riparian-buffer conservation has undergone paradigm shifts where sustainable resource use, endangered species conservation, landscape-scale connectivity, and climate resilience were incorporated into conservation planning [35,63,81].

5.1. Local Scale and Fixed-Width Buffer Zones

Fixed-width buffer zones are the most popular approach to riparian conservation, where decisions were primarily made at the state level, resulting in significant variations in buffer widths (12–52 m) throughout the United States [77]. The site-specific widths for riparian buffers were often estimated based on the maximum height of dominant plant species along the riverbanks. This baseline may be increased based on the aquatic or terrestrial community targeted for conservation. For instance, fish-bearing perennial rivers may have a buffer zone that is twice the height of the tallest tree height (~90–145 m) [82]. The scientific reasoning behind this baseline remains questionable. Nonetheless, the greater buffer-width variations stipulated by different local land managers for protection of the same target species, communities, or ecosystem functions within similar ecoregions is a significant conservation concern [20].

An array of multi-layered vegetation strips has been recommended to mitigate nonpoint-source pollution in streams associated with commercial farmlands (Figure 1). Multi-layered vegetation strips generate a gradient of structural complexity, thereby maintaining multidimensional niches for numerous taxa, including specialist foraging guilds [83]. For example, a vegetation strip dominated by graminoids and herbaceous vegetation has a rapid biomass turnover rate and thus helps restore biologically optimal soil structures. Multi-layered approaches recommended for the United States include a relatively undisturbed old-growth forest (4.5–11 m wide) closest to the stream channel, followed by managed shrub-mixed woodland layer (4–23 m wide), and a graminoid-dominant herbaceous strip mixed with shrubs and scrubs (6–8 m wide) (Figure 1) [3,18,84]. The innermost strip regulates water temperature, enhances habitat complexity and bank stability, and supplies woody debris to the aquatic core while providing critical wildlife habitats for conservation-dependent biota [40,41]. The middl e strip assimilates nutrients, retains fine sediments, and enhances groundwater recharge. The outermost strip acts as a physical barrier to storm-water runoff, reducing erosion and retaining silt, sediment, and agrochemical contaminants. Conservation Buffer Initiative—which stems from the United States Department of Agriculture Conservation Reserve Program—advocates a three-tiered design comprising perennial grasses, two rows of shrubs, and 4–5 rows of mature woody plants for rivers flowing through farmlands [85].

Numerous taxon-specific fixed-with buffer zones have been proposed for wildlife conservation in the United States. For example, buffer zones ranging from 43–290 m have been recommended for the conservation of 95% of herpetofaunal communities [20]. A forested riparian buffer of 150 m is recommended for the conservation of most North American riverine turtles, especially to support their seasonal navigations [38]. This fixed-width buffer becomes untenable for species with complex and wide-ranging life histories. For example, threatened species of riparian turtles may seek refugia as far as 400 m from the river channel they inhabit [38]. Surprisingly, fixed-width buffer zones intended to support macroinvertebrate, fish, and avian species are often smaller than those recommended for herpetofauna, ranging from a minimum of 30 m (macroinvertebrates and fishes) to 175 m (specialized forest birds) [33,86,87]. Similarly, 100–200 m riparian buffers are effective in protecting passerine assemblages and stabilizing populations of area-sensitive songbirds [88]. However, bank stability, protection of water quality, and channel heterogeneity may be achieved by much smaller buffer widths (10–130 m) and may account for >90% of regional vascular floristic richness [35,37]. Nevertheless, large buffers (>100 m) serve multiple purposes, such as mitigation of edge effects on nesting birds while providing habitats for riparian-dependent herpetofauna and small mammals [86,89,90].

Fixed-width buffers gained popularity mostly due to their administrative and operational simplicity but are ineffective to sustain ecosystem functions, metacommunity dynamics, and upland habitat associations of semiaquatic fauna [37,77]. Such singular, generic buffers are often homogenous in habitat structure and incongruent with natural processes, thereby over-simplifying riparian zones' bio-physical complexity [53]. For instance, in Canadian boreal forests, fixed-width buffers are at least partly responsible for fire suppression. Small-width homogenous buffers take longer to recover from extreme climatic disturbances and are susceptible to species invasions, insect outbreaks, and forest pathogens. Concerning multi-layered buffers, maintaining the prescribed vegetation structure may warrant intensive management interventions, which can be both financially and logistically challenging.

5.2. Watershed Scale and Variable-Width Buffer Zones

Fixed-width buffer zones are readily employable, sufficiently simple for on-ground delineation, and only warrants management interventions at the local scale. In contrast, variable-width buffer zones are more operationally complex and may necessitate land management beyond the local scale yet are effective at reaching desired conservation goals and may generate lasting benefits across broader spatial extents. For instance, watershed-wide buffer zones are compatible with systematic conservation planning designed for both freshwater and terrestrial ecosystems and align with overreaching environmental themes applicable to riverscapes. Resilience to global environmental change, prevention of nonpoint-source pollution, restoration of trophic dynamics and the riverscape continuum, mitigation of "urban stream syndrome," and augmentation of amphibian and fish biomass in urban and agricultural watersheds can be harmonized with watershed-wide riparian conservation [11,53,64,91]. At the watershed scale, buffered riparian zones support species migrations, assist movements of dispersal-limited species, augment metapopulation dynamics, thereby relieving small, declining, or isolated populations from inbreeding depression, genetic drift, and demographic stochasticity [81,92,93]. For example, streams within extensively forested watersheds yielded enhanced growth and breeding activities, greater body condition, and greater densities of rare salamanders [94]. In anthropocentric landscapes or disturbance-prone watersheds, buffered streams provide refuge for terrestrial source populations [30,31,95]. Watershed-wide riparian buffers established along a north-south orientation or elevation gradients can function as latitudinal migratory corridors aiding poleward or altitudinal range shifts in response to climate change [84].

Buffer zones delineated at the watershed scale restore connectivity integral for rivers and wetlands, including fourfold eco-hydrological dynamics: (1) lateral interactions between aquatic cores and the uplands as well as among different aquatic cores and wetlands; (2) longitudinal dynamics along the river continuum; (3) vertical linkages among the surface water, groundwater and atmosphere; and (4) temporal changes including wetland successions and modifications in channel geomorphology, hydroperiods and flow regimes [11,43,59]. Hence, watershed-wide buffer zones complement biological, hydrological, and geomorphological processes. Effective delineation of watershed-wide buffer zones requires policies that transcend administrative boundaries, focus beyond local scale conservation targets, and warrant participatory management of different jurisdictions and conservation authorities.

5.3. Determinants of Watershed-Scale Buffer Delineation

The magnitude, spatiotemporal extent, and importance of ecological functions of riparian zones depend on both large-scale watershed-wide regional properties and small-scale local habitat characteristics [96]. Thus, the delineation of riparian buffers should be a synergistic product of both local and watershed-scale factors.

Local-scale determinants include channel slope, local topographic relief, riverbank vegetation structure (e.g., stem density, basal area, vegetation successional stages), soil properties, and channel geomorphology [37,53]. Numerous field studies indicated a non-linear relationship between required buffer widths and increasing slope as well as soil erosivity, underpinning the importance of site-specific conditions in delineating buffers [17,23]. Stream order, stream width at bankful discharge, annual discharge regimes, channel dynamics (lateral channel migration and formation of oxbow or scroll lakes) and planform (the quasi-equilibrium channel morphology created by concentration or dissipation of energy and sediment movements), and floodplain complexity should also be considered [58,81,97]. For instance, buffers zones of headwater streams should be sufficiently extensive to protect riverbank seepage formations where the groundwater table approaches the surface. Concerning middle- and higher-order streams, conventional flood-risk assessments [86,87] can be utilized to determine buffer widths, thereby deterring development and industrial farming in flood-prone riparian zones. As private land managers and entrepreneurs are risk aversive, delineating high-risk flood zones as local-scale riparian buffers will carry unintended conservation benefits.

Among watershed-wide determinants—watershed size, basin-wide ecosystem processes, regional geography and climate, current and historical land-use land-cover (the extent of impervious surfaces and modified land-cover types), floodplain characteristics (presence, distribution and types of wetlands), hydrologic connectivity, spatial and temporal distribution of pollutant sources, and types of pollutants—should be accounted when delineating buffer dimensions [11,54,60]. Further, the sociocultural and socioeconomic dimensions cannot be ignored when determining the size and extent of riparian buffers, as local stakeholders must be able to connect the benefits of setting aside tracts of land with their needs and interests [78]. Riparian zones have long been shaped by both human (land-uses and resource extractions) and natural (e.g., climatic, hydrological, geomorphological, fluvial, and biological) processes. Recognizing this multidimensional co-construction will also highlight riparian buffers as an integral component of fluvial ecosystems, which may create a favorable attitude from various sectors (e.g., farmers, agroindustry, policy makers, land-use planners, and land developers) towards riparian-buffer conservation [78]. Thus, watershed-scale buffer delineations must weigh in on anthropocentric uses and values of riparian ecosystems. Both at local and watershed-scale, regional and local wildlife communities that associate riparian buffers as a critical habitat should be factored in as well. Watershed-scale buffer zonation should consider the upland dispersal and migration distance of semiaquatic fauna, which is critical for species with complex life cycles where both breeding migrations and post-natal dispersal occur over long distances [85,95,98,99].

Riparian buffers in managed timberlands should be determined based on harvest regimes, based on the total size of harvested area versus acreage of the unharvested forests in the watershed, harvesting methods, and stand age structure [31,80]. Rivers and wetlands embedded in landscapes with a prolonged land-use past, such as cattle grazing and industrial agriculture, require a lengthy recovering period as well as ample riparian reservations. Thus, land-use legacies, as well as disturbance histories across the watershed, are also critical determinants of buffer zone allocation [54,96]. Legacies resulting from anthropogenic alterations (e.g., riparian timber harvest) induce lasting changes in the entire river corridor (e.g., complete transformation of channel structure and fluvial dynamics), creating alternative states with impoverished ecosystem services [100]. Watershed-scale buffers designed to protect and restore riparian biodiversity and ecosystem functions can be more effective if the lasting effects of historical legacies are recognized.

5.4. Designs for Watershed-Scale Riparian Buffers

Olson et al. [35] proposed watershed-wide buffer conservation, which accounts for lateral and longitudinal linkages of riparian biodiversity as well as riparian-zone ecosystem functions. With the emphasis on cross-ridgeline connectivity to accommodate faunal movements among headwater streams, this conceptual model advocate for wider (200–

400 m) buffers. Olson and Burnett [84] designated ridgeline forests with a high density of headwater streams as "linkage corridors" to facilitate cross ridgeline connectivity of local biota. Dispersal aside, ridgeline forests were habitats for endemic species and harbored stable populations of native vertebrates [35,84]. Attributed to this dual function (dispersal and refugia), we proposed that "linkage corridors" be retrofitted into a riparian-buffer network. If strategically designated with ideal spatial configuration within a watershed, "linkage corridors" enhanced metapopulation interactions and assist safe passage during drought-induced movements and provided access to climate refugia in headwaters.

A two-tiered, riparian buffer design was conceptualized for headwaters of the Pacific Northwest, which can reconcile both commercial land-use operations (logging) and wildlife (amphibian) conservation [89]. Referred to as the "spaghetti-meatball approach," this design comprises non-random alternating configurations of narrow (40–150 m) and wide (400–600 m) buffers [35,92]. The narrow, long buffer strips ("spaghetti") running alongside streams encompass the moist-mesic riparian microclimates via "stream effect" while protecting strictly-aquatic and bank-dwelling species. When protected areas or other critical and rare habitats (e.g., ephemeral wetlands, fluvial lakes, old-growth stands, tributary junctions) neighbor the river channel, particularly at ridgetops, wider buffers ("meatballs") can be applied to enhance the structural heterogeneity and resource availability of the riparian environments. Narrow "spaghetti buffers" are sufficient to confer bank stability and filter runoff, thus making them suitable for streams dissecting timberlands and farmlands. High-value conservation targets, such as stream reaches with a high density of microendemic or threatened species, local hotspots of diversity, and bioclimatic refugia can benefit from "meatball buffers". The "spaghetti-meatball" design also harmonizes economically profitable, yet sustainable land uses with freshwater biodiversity conservation, hence applicable to watershed-scale riverscape conservation.

Riverscapes are spatially complex fluvial systems mosaics of habitat types and environmental gradients, interconnected by dendritic networks with unique spatial configurations and structures that differ markedly from most terrestrial systems and other aquatic systems [11,41]. The spatially heterogeneous structures of the riparian environment (including the floodplains), riparian biotic communities, and matter and energy exchange are particularly important attributes of riverscapes [7,65]. We argue that watershed-wide riparian-buffer conservation will effectively capture all critical attributes of the riverscape.

We recommend the implementation of riparian-habitat conservation criteria by Semlitsch and Bodie [25] and Olson et al. [35] to delineate buffers along river channels at the watershed scale, yet caution against abiding by the suggested buffer widths as canonical rules (Figures 2–4). Instead, we encourage re-tailoring variable buffer widths based on the spatial configuration of critical riverscape elements (i.e., floodplains, isolated channels) and niche dimensions of riparian-dependent biota of the regional species pool. The riverscape is the template for both between-habitat species turnover (beta diversity) and landscape-scale community diversity (gamma diversity); the latter metrics are prudent biodiversity targets representative of the entire riverscape [81]. Incorporating niche dimensions of riparian biotas, such as the lateral navigation distance of both philopatric and vagile species when delineating riparian zones, will make these buffers more biologically productive [90].

Hereto, we first highlight the immediate riparian zones as both core habitats of the riverscape and keystone structures of the watershed (hereafter, critical riparian core), ergo propose the first tier of buffer delineation throughout the drainage system alongside both main stems and tributaries (both perennial and ephemeral), provisionally extending into the floodplain to envelope riparian wetlands and wetland-obligate communities. These buffers can be locally distended at confluences or to connect the river channel with neighboring wetlands. The first tier should be designed to buffer the stream channel from atmospheric and terrestrial stressors, protect water sources, and enhance habitat associations of riparian and semiaquatic biota. Second, we propose delineating a critical terrestrial core beyond the critical riparian core. This second tier will promote metacommunity dynamics [91] and subdue edge effects [101]. To enhance wildlife permeability, we advise restrictions on both exploitative (subdivision or infrastructure developments, agriculture, grazing, and clearcutting) or non-consumptive (recreational) uses within the critical riparian core while permitting specific land uses (agroforestry, permaculture, forest gardening, selective logging) within the critical terrestrial core.

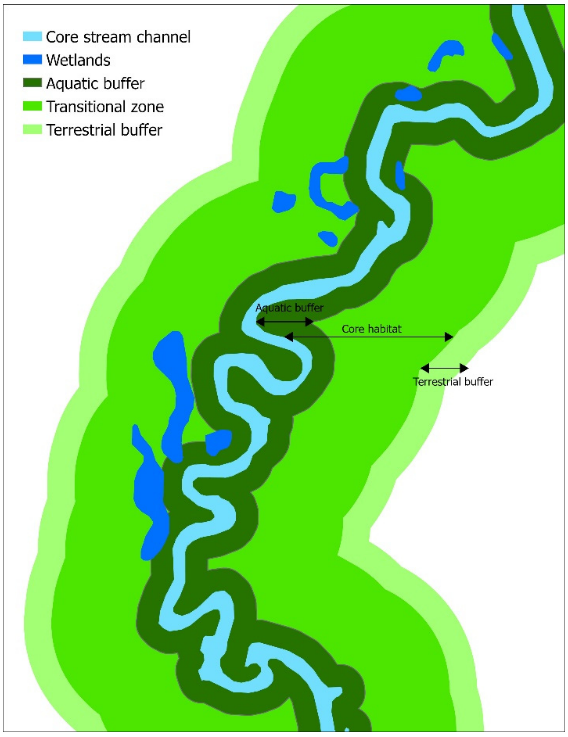

Figure 2. Fixed buffer widths applied to a single mainstem river corridor following multi-tiered buffer widths recommended by Semlitsch and Bodie [25].

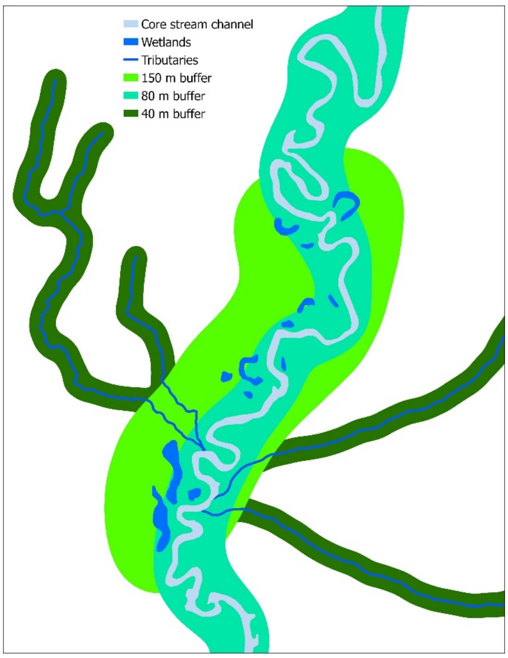

Figure 3. A variation of the Spaghetti-meatball buffer-zone delineation with variable buffer widths as recommended by Olson et al. [35,89] applied to the mainstem river corridor, including the tributaries to the mainstem.

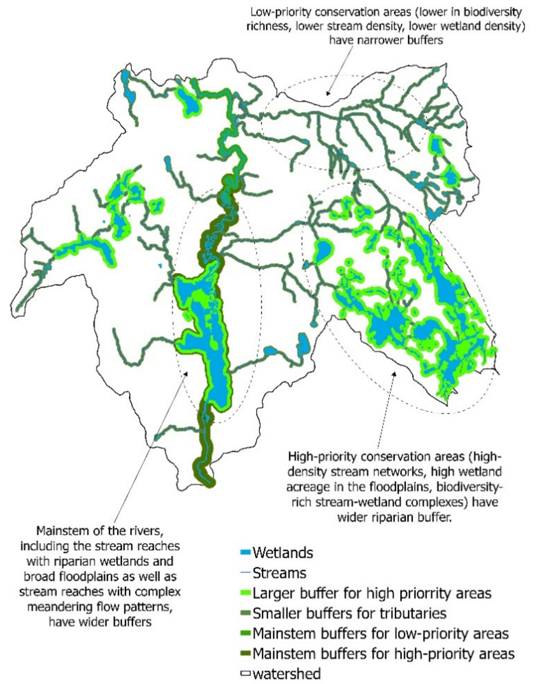

Figure 4. Variable buffer widths applied to stream channels (mainstem and tributaries) and stream-associated wetlands at the watershed scale. Increased riparian buffer widths are applied to regions with high conservation potential and other critical hydrological or ecological features to protect infertility ecosystem structure and functions.

Greater habitat heterogeneity that satisfies natural and life history requirements of riparian obligates is critical in a watershed-wide buffer delineation. Thus, we advocate the inclusion of multiple landscape elements—hibernacula, climatic refugia, high-quality foraging and nesting grounds, heterogeneous wetland complexes with variable hydroperiods, aquatic habitats that offer complementary resources, and a variety of upland habitats—into both riparian and terrestrial core habitats [93]. Moreover, we contend inclusion of forest remnants, commercial timberlands, silvopastoral systems, traditional farmlands, and restored habitats into the critical terrestrial core to reinvigorate beta and gamma diversity and to refuel metacommunity interactions and ecosystem processes [42,102].

5.5. Habitat Management within Buffer Zones

Harvested riparian zones should be characterized by mixed-aged riparian vegetation, vertical stratification, and variable successional stages, thus providing habitats for both seral and climax communities [48,103]. To promote habitat heterogeneity in the riparian buffers where historical disturbances (flooding, fire, debris flow) are suppressed, sustainable forestry operations based on various shelterwood harvesting methods, such as selective thinning in variable-sized patches, and partial cuts may generate spatial patchiness resembling natural disturbances [36,48,83]. Here, it is imperative to mimic historical disturbance regimes in terms of frequency, duration, magnitude, and spatial patterns [103]. Management decisions should weigh in the system resilience, legacy effects (historical fire regimes and grazing), climate conditions (average precipitation), and susceptibility to extreme events (windstorms, floods). A multi-use approach with regulated timber harvesting and extraction of non-woody products in designated riparian buffers will also harmonize conflicts between conservation authorities and resource users [104].

Riparian timber harvest can be connected to the multi-tiered buffer approach we proposed. No logging should be permitted within the immediate riparian zone adjacent to the stream channel (critical riparian core). Variable and transitional timber management operations forming an environmental gradient with respect to stem density, basal area, canopy closure, stand maturity, and species of interest can be permitted in outer tiers (critical terrestrial core). We urge for minimal use of machinery and motor vehicles, which leads to soil compaction and other disturbances. Availability, diversity, and size of forest-floor cover objects in the riparian buffer are crucial for ameliorating the ill-effects of logging as these cover objects preserve cool, moist microclimatic conditions for forest floor fauna [95]. Thus, we caution against salvage logging or residue removal [35,84]. However, if adequate forest-floor cover exists, some of the logging residuals can be placed alongside banks as microsites to harbor riparian vertebrates and vegetation propagules [96].

To restore longitudinal and lateral connectivity through riparian management, removal of dams, dikes, and levees is imperative to reunite river channels with floodplains and reengineer natural fluvial (meandering, braiding, anastomosing) dynamics [16,96]. Breaching artificial bank stabilization structures such as ripraps also helps restitute surface-to-groundwater movements as well as hydrologic and sediment regimes that are critical for healthy ecosystem functions of riparian zones [16,105]. Dam removal also restores both coarse- and fine-scale geomorphic features, natural flow regimes, and plant successional processes that constitute critical riparian habitats (e.g., floodplain conditions, riparian food webs, plant-community dynamics) and reduce the establishment and persistence of exotic plant species in the riparian zone [16,106,107]. Natural resource managers should estimate site-specific risks of dam removal on riparian zones (e.g., sediment aggradation on riverbanks, habitat homogenization by reducing the variability of bed elevations, biological invasions) for making informed decisions on post-restoration monitoring to detect negative impacts and implement mitigatory measures [97,105]. To improve riparian buffering functions (flood and discharge mitigation, groundwater recharge, and bioremediation), we recommend restoration of floodplain wetlands, which is particularly necessary following dam removal [108]. In impaired (urban and agricultural) watersheds with contaminated runoff, these floodplain wetlands can be an ecologically sound alternative to artificial drainage ponds.

Restoring degraded riparian zones may require the introduction of site-appropriate topsoils and subsoils with adequate soil-particle size distributions and organic matter since plant propagule recruitment, microbial remedial processes, and groundwater movements are functions of soil properties [16]. Introduction of natural cover objects across the riparian buffers in forms of woody debris in variable size and decay classes might be warranted [30,109]. We discourage "landscape manicuring"—removal of downed or standing deadwood for aesthetics and navigation. Spatial arrangement and retention of dead standing trees (snags), rock outcrops, and other vertical geological formations warrant attention as such structures serve as keystone resources for riparian fauna [98]. As degraded riparian zones are species-depauperate and periled with exotic invasions, re-introduction of foundation species (e.g., willows (Salix spp.)) and ecosystem engineers (e.g., American beavers (Castor canadensis)) as well as controlling exotic and invasive species can accelerate recovery with enhanced resilience [82,104,105].

6. Policies and Protection of Riparian Buffers

Numerous United States environmental policies contribute to riparian-buffer conservation [79]. These laws take effect via three mutually nonexclusive avenues: (1) direct acquisition or supporting acquisition of lands and waterways for buffer delineation; (2) restrictions on resource exploitation in riparian environments; and (3) develop environmental standards and guidelines to mitigate water pollution based on buffer-zone management. Herein, we will briefly review a selection of these policies, including their effects and recommendations for enhancing their impact on riparian systems.

Empowered with legislative authority on wetland and riverine buffers, the Clean Water Act (CWA) aims to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Administered by the Environmental Protection Agency (EPA) and Army Core of Engineering, the CWA recognizes pollution mitigation and provision of wildlife habitats as critical functions of riparian buffers, thus, mandates avoidance and minimization of damage to riparian zones [99,110]. We advocate that CWA's specifications on total maximum daily load, the maximum amount of a pollutant permissible in a waterbody to maintain acceptable water-quality standards, be leveraged for buffer delineation as a measure against nonpoint-source pollution [53]. We urge the CWA to recognize the riparian buffer as a "critical habitat complementary to the aquatic core" while underscoring the functional nexus between intact riparian zone and biological integrity of aquatic core habitats, thereby advocating restoration and delineation of riparian buffers as a mitigation strategy [25,26].

Administered by Fish and Wildlife Service and National Oceanic and Atmospheric Administration, the Endangered Species Act (ESA) has the potential to secure riparian environments as "critical habitats" for endangered or threatened species [111]. We encourage the inclusion of the "critical habitat" concept into a panoptic "critical riverscape" perspective to encapsulate watershed-wide environmental complexity and functional diversity inherent to riparian zones. For riparian conservation, we propose that the ESA targets umbrella species such as riparian obligates and riparian-dependent species, particularly those characterized by longevity, delayed reproductive maturity, elevated egg/larval mortality, and high sensitivity to anthropogenic disturbances [112].

Mandated by the United States Department of Agriculture (USDA), the National Forest Management Act (NFMA) requires a minimum of 30 m buffer around perennial rivers and lakes and prohibits land uses that impair water quality or fish habitats [34]. As corroborated by our review, the 30-m minimum threshold might suffice conservation of a subset of stream biota (e.g., headwaters) but is insufficient to maintain upland associations of most riparian communities. In lieu of our variable buffer-width standards, we recommend employing local and watershed-scale biophysical determinants to prescribe variables both buffer widths and length to assure watershed-wide continuity.

The National Wild and Scenic Rivers Act (NWSRA, Departments of Interior and Agriculture) aims to preserve "free-flowing" rivers with remarkable ecological and non-consumptive (aesthetic and recreational) values [39,88]. The NWSRA recommends a 400 m riparian buffer along designated rivers flowing through federal lands [113]. Given the conservation potential of these rivers, we suggest remodeling NWSRA to recognize the main stem, tributaries, and floodplains (including floodplain wetlands) of designated rivers collectively as "wild and scenic riverscape corridors" while identifying buffers as "critical life zones" of the entire watershed.

Significant extents of riparian zones in the United States are located within private lands. Further, most land development occurs within local jurisdictions where the decision-making officials are likely uninformed about local biodiversity, ecological principles, or sustainable economic benefits associated with riparian buffers [114]. As such, we highlight the urgency to educate local officials as well as private landowners on watershed-scale buffer designs [73]. To cultivate responsible stewardship among public and local officials, we recommend the introduction of citizen-science projects tailored to generate locale-specific long-term data on riparian biodiversity and ecosystem processes, which provide a scientific basis for decision making [30,115]. We also encourage repurposing citizen science as a communication hub among scientific communities, town officials, and private landowners, particularly to disseminate novel approaches on riparian conservation [43]. To enhance public buy-in, we also recommend the adoption of charismatic or flagship species that symbolize riparian habitats (e.g., river otters (*Lontra canadensis*) [102].

For watershed-wide riparian conservation to take effect, rewarding land stewards who adopt riparian best management practices are effective and prudent [78]. Administered by the USDA through the Farm Bill, a number of such programs, Conservation Reserve Program, Conservation Easements, and Environmental Quality Incentive Program, have demonstrated success in optimizing conservation potential and environmental benefits in productive agricultural lands [116]. Program participants offset environmentally sensitive lands from production and establish resource-conserving native plant species in exchange for rental payments, tax breaks, and financial and technical support for improving farming operations [85]. Our recommendations herein include educating farmers on agricultural benefits through the use of riparian buffers (e.g., flood and erosion prevention) and remodeling incentive programs for recreational entrepreneurs, the timber industry, and non-timber extraction ventures. Given the multitude of ecosystem functions originating from riparian buffers—groundwater recharge, water-quality enhancement, game species conservation, aesthetic and scenic values—we recommend enhancing incentives through Payments for Ecosystem Services for land stewards participating in riparian-buffer conservation [115].

Policy reforms for watershed-scale riparian-buffer conservation will require a paradigm shift from a conventional reach-based perspective to a more inclusive ecosystem-centered approach tailored for the conservation and restoration of hydrogeomorphological processes with the emphasis on ecological integrity and biological dynamics of rivers [117,118]. Herein, the riparian buffers should allocate more physical space to facilitate channel mobility (e.g., lateral migration, meandering) and seasonal flooding [106,118]. Such policy frameworks not only ensure sustainability and resilience of riverine biodiversity but also mitigate flood and erosion risks. Hydrogeomorphology-influenced policies have been successfully implemented in Europe and Canada [107,117]. These legislative frameworks piggyback on the notion of risk aversion (erosion and flooding) as well as ecological integrity, thus are palatable for multiple stakeholders while affording protection to critical riparian features (e.g., floodplain wetlands) and exclude development and detrimental human activities from the riparian buffers. When implemented at watershed scale, these process-driven conservation actions warrant minimal management interventions over time yet are suitable for enhancing the resilience of lotic ecosystems against global environmental change. In addition, such policies simultaneously address multiple regulatory and conservation goals such as the Habitats and Water Framework Directives of the European Union and the Clean Water and Endangered Species Acts in the US [118].

We advocate that policy reforms recognize riparian buffers not only as "critical life zones" or "core habitats" but also a vital riverine and riverscape elements crucial for biodiversity conservation and ecosystem functions [62,104]. Watershed-scale riparian conservation is appropriate for the conservation of aquatic biota, management of all forms of freshwater habitats, and resolution of competing for anthropocentric interests [11,61]. As inter-state and among-municipality collaborations are pivotal to watershed-scale conservation, we suggest that both federal and state funding mechanisms encourage such cross-jurisdictional partnerships. It is of critical importance that policymakers and scientists are cognizant of the sociocultural dimension in management decisions, as overly simplistic approaches to addressing the perceptions, needs, and interests of local communities are likely to result in conservation impasses [78]. Ultimately, if the knowledge gained through research is unable to be contextualized in a manner, which can be readily assimilated and applied, efforts, which would otherwise preserve and enhance ecosystem structure and function while simultaneously meeting the needs of the local populous are likely doomed to failure. Longitudinal and lateral dimensions inherent to watershed-wide riparian reserves will account not only local species richness (alpha diversity) but also between-habitat species turnover (beta diversity) and landscape-scale diversity (gamma diversity) [34]. We encourage state and federal conservation authorities to use these biodiversity metrics to rationalize conservation-focused decision-making.

7. Conclusive Remarks

We advocate for watershed-scale delineation of variable-width riparian buffers with multiple conservation and management objectives in place of conventional reach-scale, uniform-width approaches. Watershed-wide riparian conservation should draw from a robust ecological knowledge base and conform to the dynamics of riparian-zone ecosystem structure and functions, especially with respect to life and natural histories of local and regional species. Herein, we stress the need to protect diverse arrays of habitats—lentic, lotic, and wetland systems as well as floodplains and upland environments—to preserve landscape-scale heterogeneity, thereby configuring and enhancing connectivity. Riparian buffers are cornerstones for landscape-scale conservation planning and pave a pathway for not only riverscape conservation but also for freshwater protected-area networks. The incongruity between freshwater versus terrestrial protected areas has frequently emerged as a significant conservation challenge, yet little action has been taken to remedy this problem. Riparian buffers define an ecologically meaningful nexus between both stream channels and terrestrial environments, protect and buffer core aquatic habitats, and provide critical resources for biota along the aquatic-terrestrial continuum. Hence, riparian-buffer conservation and management, particularly when implemented at the watershed scale, may have the potential to harmonize disparate conservation goals pertinent to freshwater and terrestrial protected areas.

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The Science Behind the Need for Riparian Buffer Protection

PENNSYLVANIA LAND TRUST ASSOCIATION

Extensive scientific research documents that vegetated strips of land along waterways provide extensive water quality and other environmental and economic benefits.

Introduction

Scientific research clearly documents that riparian buffers, *particularly forested buffers and those along headwater streams*, deliver tremendous benefits. Through the interaction of their soils, hydrology, and biotic communities, riparian buffers serve many important physical, biological, and ecological functions (Klapproth, 2009).

Definition

Riparian buffers are the lands and assemblages of plants bordering rivers, streams, bays and other waterways. They directly affect and are directly impacted by the aquatic environment. Buffers have high levels of soil moisture, experience frequent flooding, and are populated by plant and animal communities that are adapted to life along the water. The boundary between the buffer and adjoining uplands is gradual and may not be well defined (Klapproth, 2009).

Degradation

The USDA Forest Service estimates that over one-third of the rivers and streams in Pennsylvania have had their riparian buffers degraded or altered, a sobering statistic when the value of their functions is considered (DEP, 2006).

Benefits

Scientific research clearly documents that riparian buffers, *particularly forested buffers and those along headwater streams*, deliver tremendous economic, ecological and other benefits. Among these benefits, riparian buffers:

- protect the quality of the water we drink;
- intercept non-point source pollutants carried by surface water runoff and remove the excess nitrogen, phosphorus and other substances that can pollute water bodies;
- stabilize stream banks and minimize erosion;
- decrease the frequency and intensity of flooding and low stream flows;
- prevent sedimentation of waterways;
- through shading, reduce swings in stream temperatures and prevent elevated temperatures harmful to aquatic life;
- provide food and habitat for wildlife of the land, water and air and allow for wildlife movement within natural corridors; and
- replenish groundwater and protect associated wetlands.

Width

The width needed for a riparian buffer to be effective depends on a number of factors, but, in general, the wider the buffer, the greater the benefits delivered.

Forested Versus Grass Buffers

Forested riparian buffers provide substantially more and better ecosystem services than grass buffers (Burgess, 2004). The roots of herbaceous and woody plants strengthen the stream bank and prevent stream bank erosion. Roots and downed trees slow the flow of stormwater and form a physical barrier to the stream or river, which allows sediment to settle out and be trapped. The forest canopy shades water, moderating water temperature. The plants are an important source of woody material in streams, which provides habitat and food for aquatic wildlife. They also provide quality habitat and food for terrestrial wildlife. These services are discussed in detail below.

Headwaters

As described in the Headwater Streams section below, research demonstrates that healthy riparian buffers along headwaters streams, both perennial and intermittent, deliver exceptionally high ecological value.

Buffer Functions

The following sections highlight key ecosystem services delivered by riparian buffers:

- reducing erosion;
- filtering sediment;
- filtering pollution;
- providing shade to moderate water temperatures;
- providing habitat; and
- storing water and reducing flooding.

Reduce Erosion

Riparian buffers reduce erosion, which both conserves topsoil and lessens the amount of sediment in streams and rivers. A buffer's roots of herbaceous and woody plants strengthen the stream bank by going through the topsoil and into a stream bank's weathered or fractured bedrock and other more stable strata. This increases the stream bank cohesiveness and adds a tensile strength that can resist shear stresses on stream bank soil (Castelle, 2000).

Filter Sediments

Riparian buffers filter sediment from stormwater runoff, reducing the amount of sediment in streams and rivers. Tree roots and downed trees slow the flow of surface water and form a physical barrier, which allows sediment to settle out and be trapped. Several studies have shown the effectiveness of riparian buffers in filtering sediment, including:

- In Blacksburg, VA, when 9.1m and 4.6m wide orchard grass buffers were exposed to shallow, uniform waterflow, they removed an average of 84% and 70% of incoming suspended solids respectively (Dillaha, Renea, Mostaghimi, & Lee, 1989).
- Over a 100-year period (1880-1979), a riparian zone of a coastal plain agricultural watershed in Georgia accumulated an estimated 190,667 to 283,276 pounds of sediment per acre per year (Lowrance, Sharpe, & Sheridan, 1986).
- In North Carolina, the movement of runoff was measured through two types of riparian buffers: a grass buffer and a buffer composed of grass, weeds and small shrubs that became an area with hardwood trees. The buffers reduced sediment load in the runoff by 60% to 90%. The effectiveness of the filters varied with the erosiveness of the watershed and storm intensity (Daniels, 1996).

Filter Pollutants

Filter Sediment, Trap Pollutants

Filtration of sediment is also important for removing chemical pollutants that bind to sediment. For example, excess phosphorus binds to soil and is found primarily in the top few inches of the soil, which are very susceptible to erosion. Trapping sediments is the most effective way to reduce non-point source pollution (Bongard, 2009).

Vegetation Removes Pollutants

Riparian vegetation removes metals, nutrients, and other chemicals from runoff via plant uptake and by facilitating bacterial degradation of the pollutants (Castelle & Johnson, 2000). Although narrow buffers can generally remove sediment in runoff, wide buffers are needed for effective nutrient removal (Dabney, Moore, & Locke, 2006).

The removal of nitrogen, a major pollutant of many watersheds, from runoff occurs almost exclusively in water-saturated zones where abundant organic matter is present. Bacteria in the buffer use nitrogen as an energy source, converting it to gas. Plant roots also absorb nitrogen in groundwater and use it for plant growth. Buffers act as a nitrogen sink when it is taken up by trees and stored in their biomass.

Multiple studies have shown that buffers are effective in removing pollutants from water:

- A study of 16 streams in eastern Pennsylvania found that forested streams were far more efficient at removing key pollutants from water than non-forested streams. In the case of nitrogen pollution, 200-800 times more nitrogen reached the stream in the non-forested segments than reached the stream in the forested segments (Chesapeake Bay Foundation, n.d.).

- In Coastal Plain, Georgia, researchers measured agricultural runoff through a 38-meter riparian buffer. The riparian buffer lowered the concentrations of atrazine and alachor by a factor of 20. Atrazine and alachor are both commonly used herbicides. Atrazine is among the most common contaminants in American reservoirs and other sources of drinking water (Duhigg, 2009).
- The degradation of the herbicide metachlor before it reaches water bodies is given extra importance because it does not readily break down in aquatic environments. It is, however, metabolized in the soil by microorganisms. It reaches water bodies by soil leaching and surface runoff. In Mississippi, the half-life of the herbicide metachlor was 10 days in a vegetated buffer as compared to 23 days in an adjacent bare field. This was likely due to a higher level of organic matter and microbial activity in the riparian strip. The enhanced degradation of metachlor in buffers may limit how much reaches water bodies (Staddon, Locke, & Zablotowicz, 2001).
- In northern Baltimore County, MD, Minebank Run flows past residential areas, corporate offices, the Baltimore beltway, a high school, and a county park before reaching the Gunpowder River. For decades, heavy volumes of stormwater running off of impervious surfaces, like roads, rooftops and parking lots, have impacted the stream. Restoration efforts included widening the riparian buffer with over 3,000 new trees and 6,000 shrubs. The restoration work, which affected nearly 3.5 stream miles, prevents up to 50,000 pounds of sediment from entering the stream annually and reduces the stream nitrogen levels by 25-50% (Lutz, 2006).

Cool Streams and Moderate Temperature Swings

The trees of riparian buffers shade the water, moderating water temperature. Temperature is a critical influence in aquatic ecosystems, affecting both the physical and biological characteristics of the stream. Changes in temperature can decrease stream biodiversity and impede animal growth. Increases in summer temperatures can increase the susceptibility of fish to pathogens; decrease food availability; alter the feeding activity and body metabolism of fish; inhibit spawning, and block spawning runs into streams (Castelle and Johnson, 2000). At the same time higher stream temperatures reduce the amount of dissolved oxygen in water; they also increase the metabolic rate of aquatic animals, increasing their oxygen needs.

In small streams, the presence of a forest canopy greatly affects the intensity of light reaching the surface of the stream. Depending on the season, light intensity in a shaded area of a stream can be 30 to 60% less than that of an exposed area (Sweeney, 1992). By limiting the amount of solar radiation that can reach a stream, trees limit both the daily fluctuations in stream temperature and the maximum stream temperatures reached (Bongard, 2009). A British Columbia study found that streams without buffers have temperatures up to 1-2 ^{o}C higher than those with buffers (Rayne, Henderson, Gill, & Forest, 2008). A study from Washington State found that non-buffered streams have maximum temperatures 2.4 ^{o}C higher than those with buffers (Pollock, Beechie, Liermann, & Bigley, 2009). In Oregon, studies of stream temperatures following the removal of riparian vegetation found that maximum stream temperatures both increased by 7 °C and occurred earlier in the summer. (Shifts in the timing of maximum temperatures, with greater increases in early summer stream temperatures, can impact sensitive stages of aquatic animals.)

Water Temperature and Chemical Toxicity

Increased water temperature increases the toxicity of many chemicals, such as ammonia. Ammonia is an inorganic form of nitrogen. It is present in water in two forms, un-ionized (NH3), which has a relatively high toxicity, and ionized (NH4+), which has a relatively negligible toxicity. As water temperatures increase, more of the ammonia is converted to the toxic un-ionized ammonia form (EPA, 1995). Polluted runoff is a large source of ammonia and nitrogen to streams (EPA, 1995). When riparian buffers are not preserved, both their ability to remove nitrogen from runoff and their ability to maintain lower water temperatures and prevent it from converting to its un-ionized ammonia form are lost.

Provide Habitat

Aquatic Habitat

Large woody debris is an essential part of stream life. It provides fish habitat and changes the stream's physical condition. Organic matter from riparian buffers, such as leaves, twigs, logs and stems that fall from the buffer into the water are a main source of food for aquatic macroinvertebrates. Aquatic macroinvertebrates are animals without a backbone, are visible with the naked eye and spend all or part of their life in the water. These animals, which include worms, mollusks, insects and crustaceans, consume the wood and the biofilms (bacteria, fungi, and algae) that form on it (Pitt & Batzer, 2011), serving as a vital link in the food web between the producers (e.g. leaves, algae) and higher consumers, such as fish.

The wood from buffers also traps additional leaf litter and wood. Macroinvertebrates use the wood as habitat, living inside the wood, under residual bark, and on surfaces that protrude out of the water. Some insects use the protruding surfaces as sites to emerge into adults or to lay eggs (Pitt & Batzer, 2011). A study of 16 streams in eastern Pennsylvania found that forested stream segments have over six times the amount of large woody debris than do grass buffered streams, even though two-thirds of the grass buffered streams were immediately downstream of forested areas (Sweeney, 1992)

Forested riparian buffers are also essential for maintaining stream and river bottom habitat. Most of the biological activity in stream ecosystems takes place on inorganic (sand, gravel, cobble, etc.) and organic (leaves, woody debris, etc.) materials on stream bottoms. Networks of tree roots, the organic debris from buffers and the variety of sizes of cobble and gravel these trap can increase the overall size of bottom habitat more than a thousand times when compared to a bare mineral soil bottom in a grass-buffered stream (Sweeney, 1992). In addition, where riparian buffers have been deforested, streams are narrower because of encroachment by herbaceous plants, mostly grasses, that would have been shaded out under forest cover, causing an additional loss of river bottom habitat (Sweeney, 1992).

Deforestation of a section of a riparian buffer can change stream bottom habitat and influence biodiversity, even if the deforested section is still vegetated. In southern Appalachia, 12 streams with deforested, but vegetated, buffers were studied. The deforested sections were up to 5.3 km long. The stream segments studied were all downslope of watersheds with at least 95% forest cover. As the length of deforested sections increased, habitat diversity decreased and riffles became filled with fine sediments (Jones, Helfman, Harper, & Bolstadt, 1999). As the length of the non-forested segments increased, overall fish abundance decreased, though the number of non-native species increased. Even in heavily forested areas, clearing a 1-3 km stretch of forested buffer was found to have substantial impacts on fish assemblages (Jones, Helfman, Harper, & Bolstadt, 1999).

Terrestrial Habitat

A broad range of mammals, birds, reptiles and amphibians rely on riparian buffers for habitat. Riparian buffers are core habitat for many semi-aquatic and terrestrial ecotone species, such as salamanders, frogs, turtles, minks, beavers and otters, and these species require a buffer that is both long and wide. Long stretches of riparian buffer also serve as wildlife travel corridors. Many birds, such as herons, fishers, eagles, and ospreys, as well as some mammals, rely on forested buffers for both habitat and resting places. These birds hunt for fish in the water and nest in adjacent forests.

For buffers to provide adequate habitat for forest dependent songbirds, they must be wide. Several studies have shown that bird species richness increases in buffers that are at least 100 meters wide and that the presence of forest dependent songbirds decreases dramatically when buffers are less than 50 meters (Bongard, 2009). For more information on the importance of protecting species richness, see the guide *Biodiversity*.

Store Water and Reduce Flooding

Riparian buffers, especially forested buffers, absorb rainwater, which recharges ground water supplies and allows storm runoff to be released more slowly. This reduces the intensity and frequency of flooding as well as allows for more water flow in streams during dry periods.

Minimum Buffer Width Needed

The minimum width needed for an effective riparian buffer depends on the function you want the buffer to serve. For example, sediment can be physically filtered out of stormwater faster than dissolved nitrogen, which requires bacterial transformation to remove it. Thus, a narrower buffer would be needed to remove sediment than that needed to remove dissolved nitrogen. Scientific studies have shown that efficient buffer widths range from 10 feet for bank stabilization and stream shading to over 300 feet for wildlife habitat. (Hawes & Smith, 2005). Necessary widths will also vary depending on site conditions, such as soil type, slope and adjacent land use and other factors. (Hawes & Smith, 2005)

In *Riparian Buffer Zones: Functions and Recommended Widths* (Hawes and Smith, 2005), the authors summarize the results of scientific studies, identifying the buffer widths needed for a buffer to effectively serve particular functions; they report the following ranges:

Erosion/sediment control	30 feet to 98 feet
Water quality:	
Nutrients	49 feet to 164 feet
Pesticides	49 feet to 328 feet
Biocontaminants (e.g. fecal matter)	30 feet or more
Aquatic habitat:	
Wildlife	33 feet to 164 feet
Litter/debris	50 feet to 100 feet
Temperature	30 feet to 230 feet

Regarding terrestrial habitat, research suggests a range of 30 to 1,640 feet. However, because the habitat needs for terrestrial wildlife vary widely, the authors do not believe it is feasible to capture the needs of all species with a uniform buffer size. They recommend reviewing information about specific animals in the targeted area as well as land conservation work at adjacent and nearby lands.

Headwater Streams

Definition

Headwater streams are the smaller tributaries that carry water from the upper reaches of the watershed to the main channel of the river. They are rarely named and are often so small that it takes little effort to jump across them. While there is no universally accepted definition of headwaters, they are often defined as first and second order streams. A stream with no tributaries, recurring or perennial, is a first order stream. When two first-order streams come together, they form a second-order stream. The Stroud Research Center defines headwaters as "tributary streams, intermittent streams, and spring seeps" (Kaplan, Bott, Jackson, Newbold, & Sweeney, 2008).

Ubiquity and Vulnerability

Headwaters represent 50-70% of the total stream miles in the U.S. (Fritz, Johnson, & Walters, 2008). Nearly everyone in the United States has a headwater stream within a mile or two of their home, leaving headwaters close to human activities such as urbanization, dams and diversions, water withdrawals, point and non-point source pollution, deforestation, and agriculture (River Keeper, 2005). The small size of headwater streams, along with their integration into the landscape, makes them highly vulnerable to degradation (Kaplan et al., 2008).

Headwater streams are not as resilient as larger streams because they lack sufficient water flow to transport and dilute sediment and pollution (Kaplan et al., 2008). Forested buffers are needed to remove pollutants from stormwater before they reach the stream. The aquatic wildlife of headwaters are usually coldwater adapted (Kaplan et al., 2008), and therefore rely on the temperature moderation effects of riparian trees. Riparian buffers are essential to the provision of food for both the headwaters themselves, and the resulting downstream food web. Riparian vegetation provides up to 90% of the organic matter (food) necessary to support headwater stream communities (Cummins & Spengler, 1978).

Essential to the Health of Water Ecosystems

Water quality, biodiversity, and ecological health of freshwater systems depend on the ecosystem services of healthy headwater streams (Kaplan et al., 2008). According to Lowe and Likens (2005),

> There is no doubt that it is important to safeguard lowland sites, but it is difficult to see how any conservation action with a goal of protecting the long-term ecological integrity and ecosystem services of natural systems, whether aquatic or terrestrial, can succeed without a foundation of intact and functional headwaters.

Headwaters are the source of much of the water, gravel, wood, and nutrients that flow through the stream network and eventually to the ocean (USDA, 2008). Headwaters can help to keep sediment and pollutants out of the stream system's lower reaches. (Kaplan et al., 2008).

Recycling organic carbon contained in the bodies of dead plants and animals is a crucial ecosystem service and is the basis for every food web on the planet (Meyer et al., 2003). In freshwater ecosystems, much of this recycling happens in small streams and wetlands (Meyer et al., 2003). This recycling process makes nutrients more biologically available to organisms downstream (Meyer et al., 2003). Headwater streams have been found to be significantly more efficient at breaking down the larger organic materials of dead plant and animals into nutrients usable to small animals, such as mayflies and caddis flies. The nutrients then work their way through the food web into larger animals downstream such as trout and birds. The processing of organic carbon in headwaters also prevents large amounts of organic material from being taken downstream, where the decomposition of large quantities could deplete dissolved oxygen levels and kill or harm aquatic life (Meyer et al., 2003).

Owing to favorable microclimate and availability of water, headwaters provide habitat for distinct assemblages of plants and animals (USDA, 2008). Hydrological conditions of many headwaters, which include running seasonally and drying out in the summer, periodically flowing underground, and frequent cascades and obstacles, lead to a lack of fish, which provides habitat that many amphibians can thrive in. Headwaters act as refugia for riverine species during specific life-history stages and critical periods of the year, such as warm summer months (Lowe & Likens, 2005).

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The Pennsylvania Land Trust Association would like to know your thoughts about this guide: Do any subjects need clarification or expansion? Other concerns? Please contact Andy Loza at 717-230-8560 or aloza@conserveland.org with your thoughts. Thank you.

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