Stabilizing three miles of unpaved roads on Culebra Island

Final Report for PO 275

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Summary

The successful implementation of this project has led to the stabilization of three miles of previously unpaved roads on the island of Culebra. Protectores de Cuencas (PDC), in collaboration with the National Oceanic and Atmospheric Administration (NOAA), the municipality of Culebra and local citizens stabilized roads strategically located within the priority watersheds of Coronel, Cabra, and Carenero. The initiative aligns with the objectives outlined in the Culebra Watershed Management Plan and corresponds to NOAA's key priorities in safeguarding the coastal ecosystems of Culebra.

Anticipated outcomes include a significant reduction in the annual production and delivery of sediment to the nearshore ecosystems of Culebra, estimated to range between 50,000 to 125,000 pounds. This accomplishment not only contributes to the ecological well-being of the region but also represents a substantial step towards achieving the broader conservation goals outlined in the ***Culebra Community Watershed Action Plan for Coral Reefs and Water Quality***.

Background

Water quality degradation resulting from unsustainable development practices stands out as a significant threat to near-shore ecosystems, amidst numerous global, regional, and local stressors (Otaño-Cruz et al., 2019). Particularly in coastal watersheds, this degradation is identified as a paramount concern, with implications for vital ecosystems such as coral reefs, beaches, and seagrass meadows that play a crucial role in Culebra island's economy. Regrettably, the near-shore ecosystems in Culebra face persistent jeopardy from anthropogenic stressors, including untreated sewage water and trash. However, a notable and recurring threat emerges from sediment-laden runoff generated by unpaved roads.

The escalation of terrigenous sediment into coastal waters amplifies turbidity levels, diminishing the availability of photosynthetically available radiation (PAR) crucial for organisms like seagrass and corals. The adverse effects extend to increased vulnerability and susceptibility of coral reefs, potentially leading to a shift towards non-reef building taxa and macroalgal assemblages in some instances (Hughes et al., 2010). Sedimentation stress is associated with localized partial coral mortality, reduced coral growth rates, inhibited larval settlement, and compromised fish grazing (Fabricius, 2005; Rogers and Ramos-Scharrón, 2022). Furthermore, coral reefs facing recurrent sediment pulses and heightened turbidity struggle to recover from chronic disturbances such as bleaching caused by elevated sea surface temperatures and increased prevalence of coral diseases (Toledo-Hernández et al., 2007). Furthermore, the settling of fine sediment particles on corals enhances bacterial activity, exposing corals to dissolved substances, trace metals, and contaminants like pesticides adhering to clay minerals (Rogers and Ramos-Scharrón, 2022).

In Culebra, multiple field studies, modeling efforts, and anecdotal evidence have identified the unpaved road network as the primary source of sediment (Collazo et al., 1992; Hernández-Delgado, 1992 Ramos-Scharrón et al., 2012; Otaño-Cruz et al., 2017; Gómez-Andújar and Hernández-Delgado, 2020). Erosion rates from unpaved roads have been documented at up to four orders of magnitude higher than natural rates and ranging from 11.6 to 26.8 Mg $ha^{-1}yr^{-1}$ (Ramos-Scharrón et al., 2023, in press). This stark contrast in sediment delivery from roads compared to other land uses, coupled with the absence of widespread landsliding on the main island of Puerto Rico (Rogers and Ramos-Scharrón, 2022), underscores the critical role of the road network in sediment-related concerns.

Moreover, the small size and steepness of watersheds in Culebra, combined with low erosion rates from undisturbed areas (~0.035 Mg $ha^{-1}yr^{-1}$), accentuate the potential for land disturbance to drastically increase erosion, even with relatively limited development or land-use changes (Ramos-Scharrón and MacDonald, 2007b). Consequently, the prioritization of unpaved road stabilization emerges as imperative in mitigating land-based pollutants, as outlined in the Culebra Watershed Management Plan and endorsed by NOAA. Recognizing this, the call to stabilize unpaved roads transcends a mere environmental management strategy; it becomes a linchpin in preserving the ecological integrity of Culebra.

Site Selection

Evaluation of the Original Roads

In August 2020, Horsley Witten Group issued the NOAA Order of Services 275, soliciting assistance from PDC to address the stabilization of 3 miles of dirt roads situated in watersheds prioritized for unpaved road stabilization in the island of Culebra in Puerto Rico. Using priorities identified between 2013 and 2018, PDC initially identified 3.6 miles of road segments for stabilization, as illustrated in Figure 1. However, in recent site assessments, it became evident that several of these segments posed feasibility challenges for stabilization.

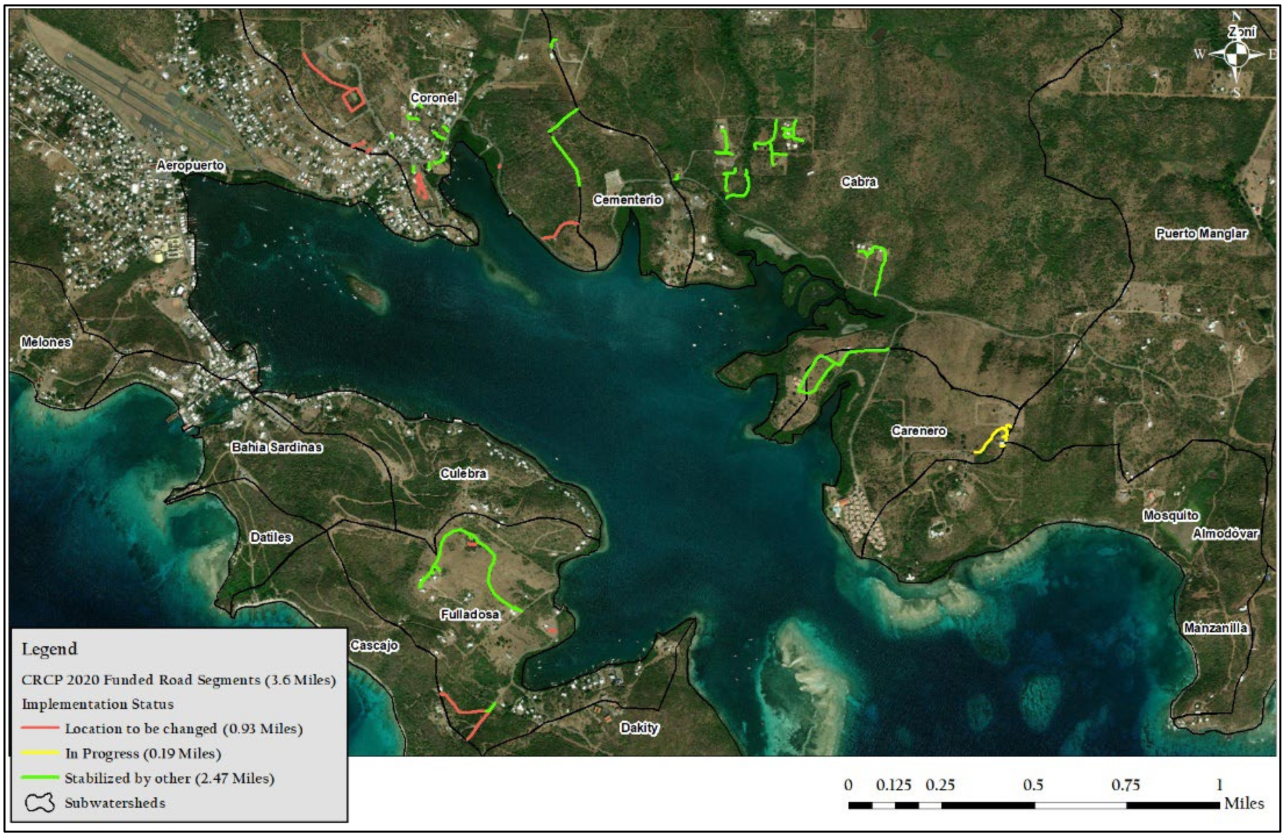

Figure 1 Initial selection of roads to stabilize for Purchase order 275.

Various impediments, including access-related complexities and instances where road segments had already undergone stabilization for reasons unrelated to PDC initiatives (such as being stabilized by landowners or being abandoned), prompted the reconsideration of the originally designated road segments. As part of our field evaluation 3.6 miles of roads were surveyed and grouped into three categories, *'Location to be changed', 'In Progress' and 'Stabilized by other'*. *'Location to be changed'* refers to road segments substituted based on factors such as access challenges and feasibility concerns; *'Stabilized by other'* refers to roads that were stabilized by efforts unrelated to PDC; and *'In Progress'* refers to those selected for stabilization.

According to the results, a staggering 74% of the road segments had already undergone stabilization efforts by other means. Additionally, 19% of the segments necessitated relocation due to issues related to access or feasibility. A minimal 5% (or 0.19 miles) of the roads originally proposed were deemed feasible for stabilization, as indicated in Table 1.

Table 1 Selected roads summarized by the implementation Status

Implementation Status	Road Length (Miles)	Percentage of Total Miles
In Progress	0.19	5%
Location to be changed	0.93	26%
Stabilized by other	2.47	69%
Grand Total	**3.59**	**100%**

Given the scope of the 'stabilized by other' roads category, PDC conducted a thorough examination to characterize the various methods employed for road stabilization. The accompanying map (Figure 2) visually delineates the diverse stabilization processes that the roads have undergone.

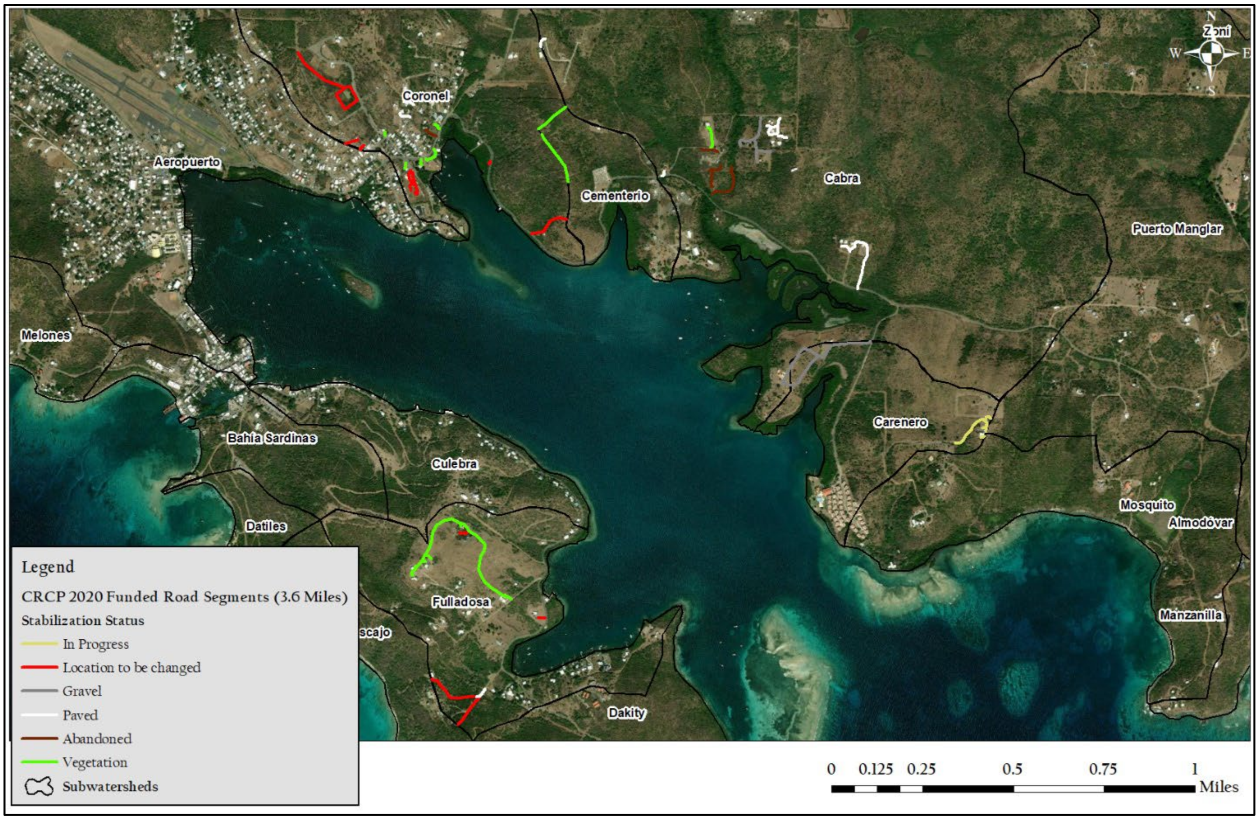

Figure 2 Roads categorized by their stabilization status.

A significant portion, constituting 27%, underwent stabilization through the natural growth of vegetation (Figure 3). Following closely were roads stabilized with gravel (18%) and those paved (14%) (Figure 4). Additionally, 10% of the roads fell under the category of abandonment, indicating that they were no longer accessible for car travel.

Table 2 Roads categorized by their stabilization status.

Stabilization Status	Road Length (Miles)	Percentage of Total Miles
Abandoned	0.36	10%
Gravel	0.65	18%
In Progress	0.19	18%
Location to be changed	0.93	26%
Paved	0.49	14%
Vegetation	0.97	27%
Grand Total	**3.59**	**100%**

Figure 3 Example of abandoned and paved roads categorized as stabilized by other.

Figure 4 Examples of vegetated and paved roads categorized as paved by others.

Surprisingly, the majority of changes in road selection stemmed from the fact that the roads were already stabilized by other entities, underscoring how dynamic is the shift in land cover changes associated to roads in Culebra. The intricate interplay between various entities involved in road stabilization underscores the need for adaptability and strategic decision-making in navigating the evolving landscape of conservation efforts.

Selection of new roads

Upon realizing the challenges posed by the original roads for stabilization, PDC used supplementary site assessments and spatial analysis to identify a new set of unpaved roads for stabilization. Through this comprehensive exercise, PDC identified and selected a total of 3.7 new miles strategically situated within the Coronel, Cabra, and Carenero watersheds, where the original roads were located (Figure 5).

Remarkably, the lion's share of this revised selection, accounting for 2.88 miles or a substantial 77%, is concentrated within the Coronel watershed, as detailed in (Table 4). The distribution of the remaining roads reflects an equitable allocation between the Cabra and Carenero watersheds. This strategic realignment underscores PDC's commitment to precision and adaptability, ensuring that the revised selection aligns seamlessly with the nuanced dynamics of the local terrain and conservation priorities. Examples of some of the new selected roads are illustrated in Figure 6 and Figure 7.

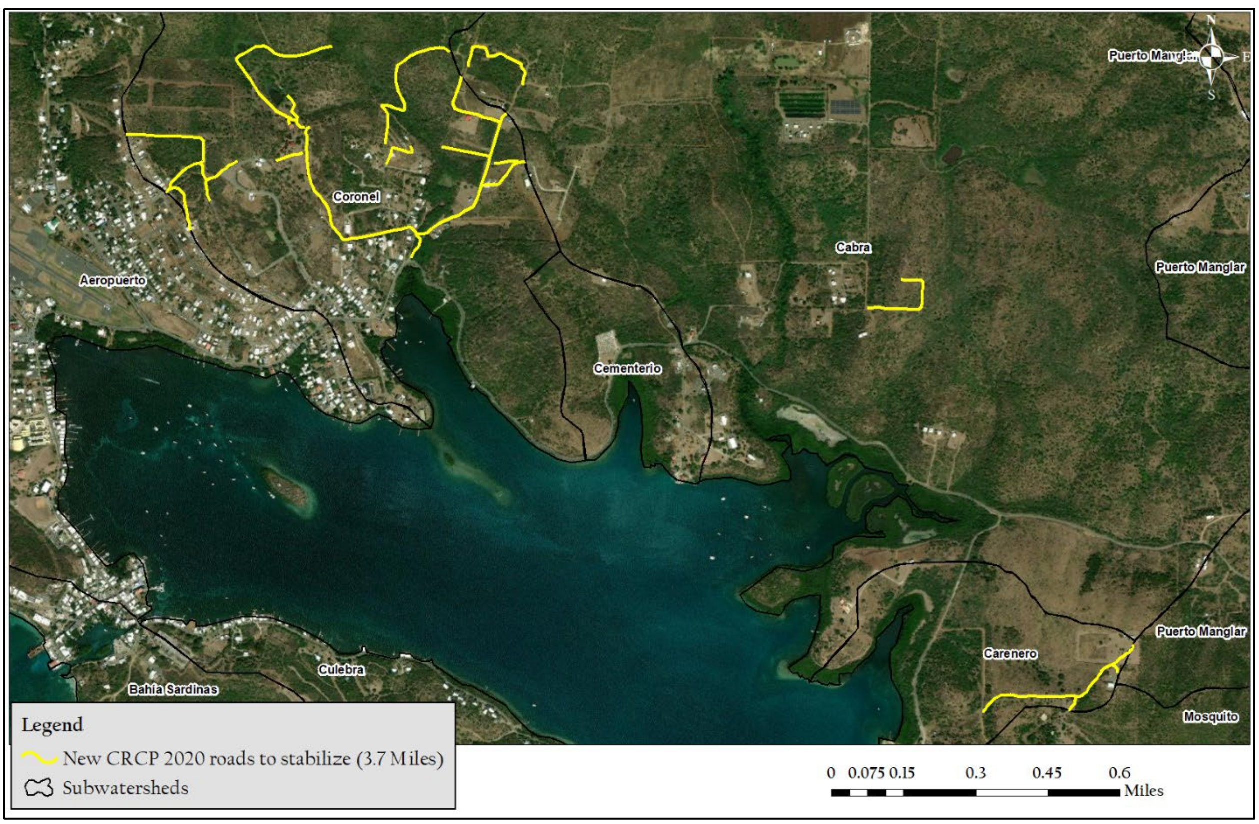

Figure 5 New selected roads to stabilize.

Table 3 New roads to stabilize by subwatershed

Subwatershed	Road Length (Miles)	Percentage of Total Miles
Cabra	0.42	11%
Carenero	0.44	12%
Coronel	2.88	77%
Grand Total	3.73	100%

Figure 6 New selected road in the Carenero watershed.

Figure 7 New selected road in the Cabra watershed.

Implementation

While sediment delivery from watersheds to coastal waters is intricately governed by multifaceted processes, it essentially represents a delicate equilibrium between the mass of sediment eroded and that effectively retained by sediment sinks. These sinks, comprising features like floodplains, salt ponds, and coastal wetlands (de Vente et al., 2007), play a pivotal role in the overall sediment dynamics within an ecosystem. The focal point of the road stabilization initiative is to disrupt this delicate balance deliberately, aiming to curtail sediment delivery by amplifying the capacity of sediment sinks strategically positioned in the drainage areas associated with the targeted road segments.

The overarching strategy deployed to achieve road stabilization encompasses a comprehensive approach. This involves not only mitigating erosion rates but also engineering improvements in road drainage systems. Additionally, efforts are directed towards rerouting runoff away from vulnerable areas, diverting it towards hillsides to promote infiltration and in some cases to ephemeral streambeds that allow sediment deposition. The intended outcome is a tangible reduction in the frequency and magnitude of sediment delivery to coastal waters, thereby alleviating the stress on near-shore ecosystems.

A suite of Best Management Practices (BMPs) are integral components of road stabilization efforts. These include the construction of ditches, swales, turnouts, check dams, step pools, sediment traps, cutslope stabilization measures, vetiver grass and tree planting, and other innovative measures designed to minimize erosive forces and capture sediment before it reaches critical coastal zones. By strategically incorporating these BMPs, the initiative seeks not only to mitigate the immediate impact of sediment-laden runoff but also to foster sustainable land-use practices that resonate with the broader goals of environmental conservation.

Prior to commencing any stabilization efforts in the designated area, PDC took proactive measures by implementing a set of temporary sediment and erosion control practices. These were strategically placed along the existing road and in proximity to the coastal zone, as well as in areas earmarked for upcoming work. Among the sediment control practices employed were the installation of silt fences and soil berms, positioned to redirect filtered runoff towards forested regions.

A pivotal step preceding the implementation of Best Management Practices (BMPs) involved regrading and compacting the road (Figure 8 and 9). The regrading procedure was executed with precision using a Crawler dozer, while soil compaction was achieved using a 15-ton compacting roller. This critical undertaking aimed to establish the desired hydrological patterns conducive to effective sediment control. The runoff was channeled into continuous swales, featuring 4-12” stones, and supplemented with Vetiver grass check dams strategically spaced at intervals ranging from 25 to 50 feet, contingent on the specific slope conditions.

Figure 8 Grading and compaction of road prior to implementation of BMPs.

Figure 9 Grading, compacting and ditch construction at Coronel watershed, road segment CO-21B.

Roads were graded to ensure a slope conducive to directing runoff towards the constructed ditch and into the installed Best Management Practices (BMPs). Ditches play a vital role in channeling runoff away from the road travel lane and guiding it towards check dams, where its velocity and erosive energy are reduced, facilitating sediment deposition. These check dams are crafted using stones and reinforced with vetiver to enhance structural stability. In road segment CA-11 within the Cabra Watershed, this strategic approach was implemented, as depicted in Figures 10 to 12. These figures provide visual documentation of the application of this methodology, illustrating the integration of graded roads, ditches, and check dams in mitigating erosion and managing runoff effectively.

Figure 10 Stabilized road segment (CA-11) in Cabra Watershed. The road was insloped to a ditch and check dams were located in the ditch. The cutslope was protected with an erosion control mat. Left picture: Looking upslope. Right picture looking downslope.

Figure 11 Check dams finalized and with planted vetiver at road segment CA-11 in Cabra watershed. Note the cutslope stabilized with an erosion control mat.

Figure 12 Check Dams and sediment detention pond being constructed in road segment Carenero-2.

Another important feature of dirt roads are cutslopes. However, these cutslopes, characterized by their steep gradients and inherent instability, pose a notable challenge by generating substantial amounts of sediment. In segments where ditches and check dams are strategically installed, a unique concern arises—erosion from cutslopes has the potential to compromise the functionality of these BMPs by causing clogging and redirecting runoff off the ditch and into the road bed. To proactively address this issue, erosion control mats, proven to be an effective measure in curtailing cutslope erosion, were judiciously deployed in select instances (Figure 13).

Figure 13 Stabilized cutslope with erosion control mat.

Another crucial Best Management Practice (BMP) implemented in this project was the construction of swales. Swales are depressions strategically created to intercept concentrated runoff, mitigating its erosive force. Through careful excavation and the placement of stones, these swales facilitate infiltration and reduce runoff velocity. The primary objective of these swales is to redirect significant volumes of runoff towards stable outlets, such as forested areas or sediment traps, where sediment deposition can occur.

Sediment traps stand as indispensable components in the effort to safeguard sensitive areas from sedimentation. These engineered structures are designed depressions situated at lower elevations, serving as temporary reservoirs to detain runoff. Within these traps, sediment settles out of the water column, aided by the controlled ponding effect. Reinforced with rock embankments and outfitted with stable outlets or spillways, sediment traps ensure that runoff is released gradually and in a controlled manner. Figures 14 to 21 offer tangible illustrations of the swales and sediment traps constructed as part of this project.

Figure 14 Swale redirecting runoff to forested area at Cabra Watershed (Segment CA-11).

Figure 15 Installation of geotextile and berm to construct inlet to sediment trap at Carenero watershed in road segment Carenero-2.

Figure 16 Sediment Traps and swales constructed in Coronel watershed in Segment CO-21B.

Figure 17 Sediment Traps and swales constructed in Coronel watershed in Segment CO-21B.

Figure 18 Sediment Trap installed at Carenero watershed in road segment Carenero-2.

Figure 19 Sediment Trap designed to receive runoff from ditch with check dams at Carenero-2 road segment.

Figure 20 Sediment trap and stabilized outlet and swale constructed at Coronel watershed road segment CO-21B.

Figure 21 Evidence of sediment traps at Coronel watershed (CO-21B) receiving runoff and sediment.

Budget

The total cost of the project amounted to $314,510.00, with PDC contributing nearly 30% through in-kind contributions. A significant portion of the project expenditure (55%) was allocated to supplies and general labor, which are fundamental components critical for project execution. Notably, PDC's contribution covered over 70% of Equipment Rental and Travel and Lodging expenses, resulting in substantial savings for the project.

Table 4 Project budget with expenses summarized by categories and in-kind contributions.

Task	Cost	PDC In-kind
Project Management and Coordination	$ 16,000.00	$ 6,200.00
General labor	$ 58,310.00	
Supplies	$ 117,000.00	
Equipment Rental	$ 28,400.00	$ 52,000.00
Travel and Lodging provided by PDC and Municipality	$ 4,600.00	$ 32,000.00
Totals	*$ 224,310.00*	*$ 90,200.00*
Grand Total	***$314,510***	

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