Sea Buckthorn (*Hippophae* spp.) in the Indian Himalayas: Integrating ethnobotanical knowledge, phytomedicinal potential, and conservation strategies

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Review

Abstract

Background: The Indian Himalayan Region (IHR), a globally biodiversity hotspot, is ecologically vulnerable, requiring sustainable use of its native resources. Sea buckthorn (*Hippophae* spp.) is a keystone multipurpose shrub widely distributed across the IHR, valued for its ethnobotanical relevance, phytomedicinal potential, and ecological functions. However, a comprehensive synthesis integrating traditional knowledge, bioactive composition, and conservation challenges remains fragmented.

Methods: A systematic review was conducted following PRISMA 2020 guidelines to synthesize existing scientific evidence on *Hippophae* spp. in the IHR. A structured literature search was performed in the Scopus database for peer-reviewed articles published between 2000 and 2025. After screening and eligibility assessment, 48 studies were included for qualitative synthesis focusing on ethnobotanical applications, phytochemical composition, ecological roles, and conservation status.

Results: Sea buckthorn is extensively utilized across Himalayan communities for food, traditional medicine, fodder, and livelihood support. It is rich in bioactive compounds, including vitamins, carotenoids, flavonoids, polyphenols, phytosterols, and essential fatty acids, conferring antioxidant, anti-inflammatory, cardioprotective, hepatoprotective, and dermatological properties. Ecologically, the species enhances soil stabilization, improves moisture retention, and contributes to the restoration of degraded landscapes. Despite its multifunctional value, natural populations are increasingly threatened by overexploitation, habitat degradation, weak regeneration, erosion of indigenous knowledge, and climate change.

Conclusion: Sea buckthorn represents a critical bioresource linking traditional healthcare systems with ecosystem resilience in the IHR. Integrating community-based conservation, sustainable harvesting practices, germplasm preservation, and value-addition strategies is essential to ensure its long-term sustainability and role in climate-resilient development.

Keywords: Ethnobotanical uses, *Hippophae*, Indian Himalayas, Sustainable Conservation, Nutritional composition, Bioactive compounds.

Background

The Himalayan range, often referred to as the "Third Pole", represents one of the planet's most critical ecological and climatic zones. The IHR, home to some of the most ecologically unique and fragile cold desert landscapes primarily occupies the Trans-Himalayan zone characterized by severe seasonal extremes, intense aridity, and nutrient-poor soils (Aswal and Mehrotra 1994; Sharma 2011; Kaler *et al.* 2024). These cold deserts are home to limited but ecologically significant flora uniquely adapted to extreme cold, low atmospheric pressure, high solar radiation, and persistent winds (Kumar *et al.* 2020; Sharma *et al.* 2024).

A critical biodiversity hotspot, the region contains a vast range of endemic flora and fauna, possessing specialized physiological traits evolving under prolonged environmental stress (Singh and Rawat 2021; Iqbal *et al.* 2024). This biodiversity is vital not only for maintaining ecosystem functions but also for sustaining local livelihoods (Joshi *et al.* 2020; Chhetri *et al.* 2022; Ullah, 2025). However, the ongoing climate crisis presents challenges in the form of temperature fluctuations, altering precipitation regimes, and increasing frequency of droughts (Karki *et al.* 2019; Sherpa *et al.* 2022). These dynamics destabilize fragile mountain ecosystems, accelerating soil erosion, reducing vegetation cover, and threatening endemic species (Thakur *et al.* 2021; Tsering and Lama 2023). Conservation and management strategies informed by a sound understanding of these ecological processes and the region's floristic diversity are critical to safeguarding the IHR's biodiversity heritage (Bhatt *et al.* 2022; Pandey *et al.* 2023). With projections indicating over 3 °C temperature rise by the end of this century, (Singh *et al.* 2010) there is an urgent need for ecological restoration measures that can both stabilize fragile landscapes and sustain local communities.

Within this fragile yet biodiverse mountain ecosystem, Sea buckthorn (*Hippophae* spp., family Elaeagnaceae) emerges as a keystone multipurpose shrub of considerable ecological, economic, and ethnomedicinal value. The scientific name *Hippophae* originates from the Latin words *hippo* (horse) and *phaos* (shine), meaning "shining horse". As per the historical accounts, soldiers in Alexander the Great's army observed that feeding Sea buckthorn leaves and berries to weak or injured horses restored their vitality and gave their coats a healthy shine (Small *et al.* 2002; Doukas 2023, Stodan 2024). Sea buckthorn is a temperate, deciduous, and spiny shrub widely recognized as a source of medicine, fodder, and fuelwood among local communities inhabiting high-altitude regions (Husain *et al.* 2018). It typically grows 2-4 meters tall with narrow, silvery-green leaves tolerating temperatures from –43 °C to +40 °C (Sharma *et al.* 2019).Being dioecious in nature, it relies on wind pollination for fruit development and produces clusters of small, soft yellow to orange fruits rich in nutrients (Stobdan *et al.* 2011). Its common name, "Sea buckthorn," reflects its natural tendency to thrive near coastal areas and its resemblance to the thorny buckthorn species of the genus *Rhamnus*.

The genus *Hippophae* L. comprises six species (Zore *et al.* 2025), namely *Hippophae rhamnoides* L., *Hippophae salicifolia* D. Don, *Hippophae tibetana* Schltdl., *Hippophae x goniocarpa* Y.S.Lian & al. ex Swenson & Bartish, *Hippophae gyantsensis* (Rousi) Y.S. Lian, and *Hippophae neurocarpa* S.W. Liu & T.N. He, along with twelve identified subspecies. Its distribution within the IHRis restricted to three taxa, namely *H. salicifolia*, *H. rhamnoides* subspecies *turkestanica*, and *H. tibetana* (Sharma *et al.* 2019). Large, naturally occurring populations of *H. rhamnoides* have been reported from several sites in Spiti valley, such as Tabo (3390 m), Shichling (3520 m), Lingti (3560 m), Shego (3615 m), Rangrik (3790 m), and Hansa (4040 m) (Sharma 2011; Sharma and Singh 2017).

Traditionally, Himalayan communities have utilized sea buckthorn for food, medicine, fuel, and fodder (Rongsen 1992; Zhang 2000; Small *et al.* 2002; Kania-Dobrowolska *et al.* 2023). More recently, its role in soil binding, prevention of erosion and land rehabilitation has increased its importance with respect to conserving fragile cold desert landscapes (Kaler *et al.* 2024). The incorporation of sea buckthorn into afforestation drives has numerous benefits including soil stabilization, nutrient enrichment and increased means of livelihood through value added products. Sea buckthorn possesses incredible stress resilience; a trait that opens a world of opportunities for developing cold-resistant crops that may enhance agriculture yield in high altitude climatically harsh regions (Husain *et al.* 2018). The importance of *Hippophae* as an extremely valuable medicinal plant has been underscored by numerous recent studies. It is widely known for its antioxidant and antimicrobial effects (Nowak *et al.* 2022; Wang *et al.* 2022) in addition to its role in regulating glucose metabolism and lipid levels of blood (Chen *et al.* 2023; Geng *et al.* 2022).

According to the studies, *Hippophae* has substantial pharmacological potential because of its diverse bioactive compounds. Research has emphasized its broad-spectrum pharmacological activities, including the reduction of triglycerides and LDL cholesterol and promoting skin repair and protection (Visan *et al.* 2023; Kopčeková *et al.* 2023; Laskowska *et al.* 2022; Zhou *et al.* 2023; Skowrońska and Bazylko 2023). Despite its many health, ecological, and socioeconomic benefits, research on *Hippophae* is still dispersed and extensive. This limited a comprehensive knowledge of its overall potential by concentrating on discrete aspects (Suryakumar and Gupta 2011; Wang *et al.* 2022)

There is a clear need for integrated assessments linking ethnobotanical knowledge, spatial distribution, ecosystem services, conservation status, and climate change vulnerability, particularly in the cold desert ecosystems of the IHR (Husain *et al.* 2018; Sharma *et al.* 2019; Nybom *et al.* 2023). While Ladakh and parts of Himachal Pradesh have received comparatively greater attention, other Himalayan states such as Uttarakhand, Sikkim, and Arunachal Pradesh remain underrepresented in consolidated evaluations of traditional uses, population status, and region-specific threats (Basistha 2009; Dhyani *et al.* 2010; Vairale *et al.* 2020). These gaps, coupled with habitat fragmentation, overexploitation, erosion of indigenous knowledge, and climate-driven distribution shifts, highlight the need for a comprehensive, region-focused review to support evidence-based conservation and sustainable utilization of *Hippophae* spp. in the Indian Himalayas (Dhyani *et al.* 2010; Nybom *et al.* 2023).

Considering the growing interest worldwide in plant-based medicines, nutraceuticals, and functional foods, sea buckthorn is an effective phytomedicinal resource due to its rich phytochemical composition and wide range of medicinal potential (Criste *et al.* 2020; Dubey *et al.* 2024; Dong *et al.* 2025). By combining ecological, phytomedicinal, and ethnobotanical perspectives, the potential of sea buckthorn as an important plant for sustainable bioresource, phytopharmaceutical development, and nutraceutical research in the Himalayan region is highlighted in this work.

Although this study primarily focuses on the IHR, certain studies from broader Himalayan, trans-Himalayan, and global contexts were also taken into consideration when needed to offer comparative insights into the pharmacological characteristics, phytochemical composition, conservation significance, and ecological functions of *Hippophae* spp*.* Results relevant to Himalayan communities in India were contextualized and strengthened by the use of such comparative evidence.

Therefore, this review aims to:

(i) assess the current global and Indian distribution of *Hippophae* spp.

(ii) comprehensively examine the phytomedicinal, ethnobotanical knowledge and traditional uses of *Hippophae* spp. In IHR

(iii) evaluate ongoing conservation efforts and persisting challenges associated with *Hippophae* spp. in IHR.

This study emphasizes the significance of sea buckthorn as a possible phytomedicinal, ecological, and nutraceutical relevant species in the Himalayan area by combining ethnobotanical knowledge, pharmacology, phytochemistry, clinical data, and conservation viewpoints.

Materials and Methods

Review Protocol and Search Strategy

This study was conducted as systematic review following the PRISMA (2020) guidelines to ensure transparency and reproducibility (Page *et al.* 2021). The review aims to synthesize the scientific evidence on *Hippophae* spp. in the IHR with focusing on ethnobotanical uses, phytochemical composition, ecological and conservation aspects. A comprehensive literature search was performed using Scopus database due to its large coverage of peer-reviewed scientific publications. The search string was developed using Boolean operators and truncation symbols, combining taxonomic, geographical, and thematic keywords. Both general and species-specific terms were included to ensure comprehensive extraction of related studies applied to the title, abstract, and keywords. The final search string was: TITLE-ABS-KEY ("sea buckthorn" OR "sea buckthorn" OR "*Hippophae*" OR "*Hippophae rhamnoides*" OR "*Hippophae salicifolia*" OR "*Hippophae tibetana*" OR "*Hippophae goniocarpa*" OR "*Hippophae gyantsensis*" OR "*Hippophae neurocarpa*") AND TITLE-ABS-KEY ("Indian Himalaya*" OR "Himalayan region" OR "Trans-Himalaya*" OR "Ladakh" OR "Himachal Pradesh" OR "Uttarakhand" OR "Sikkim" OR "Arunachal Pradesh") AND TITLE-ABS-KEY ("ethnobotan*" OR "traditional use*" OR "medicinal use*" OR "phytochem*" OR "bioactive compound*" OR "nutrition*" OR "ecology*" OR "distribution" OR "conservation" OR "climate change") AND PUBYEAR > 1999 AND PUBYEAR < 2026. The search was limited to peer reviewed articles published in English between the time period 2000 to 2025. These filters were applied at the database level and are shown in the initial number of retrieved records.

Study Selection, Eligibility Criteria and Data Synthesis

The study selection process followed the PRISMA 2020 framework (Figure 1). A total of 90 records were initially identified through the database search. After removal of duplicate records (n=8), 82 records were retained for screening. Titles and abstracts were screened for relevance, resulting in the exclusion of 22 records that did not meet the predefined inclusion criteria. Consequently, 60 full text articles were assessed for eligibility. During this evaluation, 12 articles were excluded due to lack of relevance, insufficient data and absence of thematic alignment with the study objectives. Finally, 48 articles were included in the qualitative synthesis.

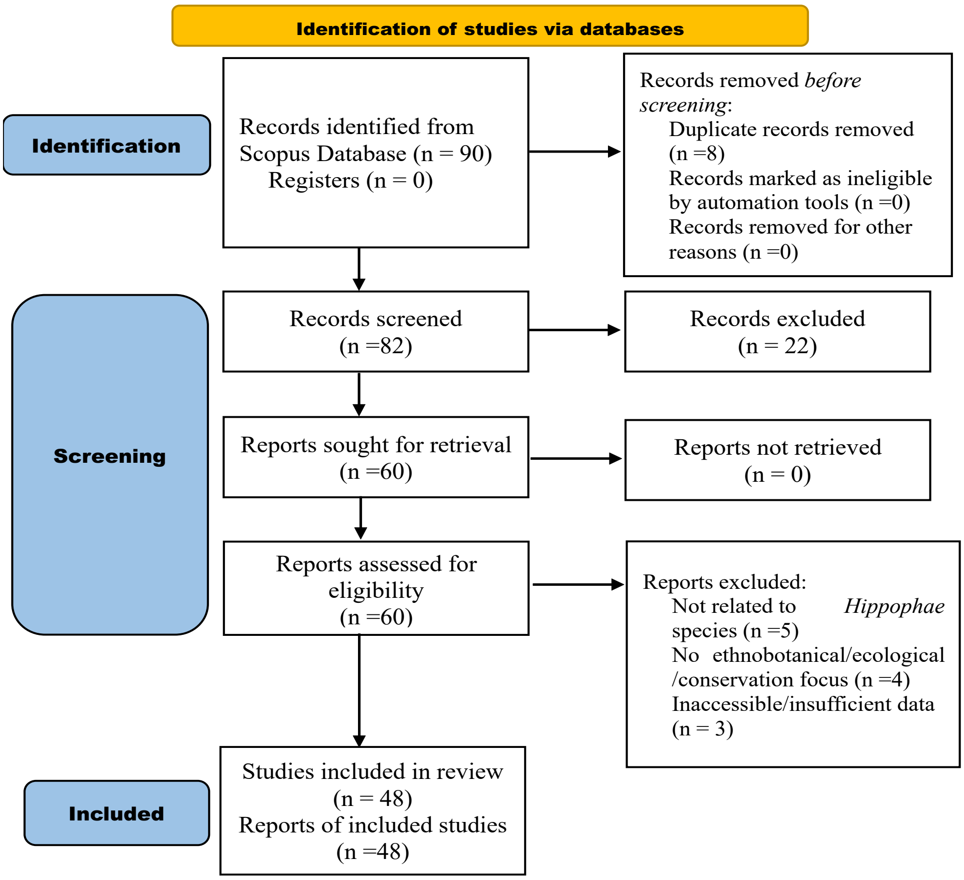

Figure 1. PRISMA flow diagram for systematic review

The inclusion criteria are comprised of studies focusing on *Hippophae* spp. within the IHR addressing ethnobotany, phytochemistry, ecology, or conservation aspects while exclusion criteria included non-English, conference, grey literature, book chapters, duplicate records and studies missing full text access and direct relevance. The data extraction was conducted using structured framework, including variables such as species studied, geographical distribution, study design, ethnobotanical uses, phytochemical composition, ecological roles, and conservation status. Due to this variation among studies, a qualitative comprehensive synthesis approach was adopted to identify patterns, research gaps and future directions. All screening and selection steps were performed manually, and no automation tools were used.

Results and Discussion

Taxonomy

The genus *Hippophae* L. belongs to the family Elaeagnaceae and comprises six to seven recognized species with several subspecies distributed across temperate and alpine regions of Eurasia (Li and Schroeder 1996; Bartish *et al.* 2002; Liu and He 2020). Taxonomically, the genus is characterized by deciduous, thorny shrubs or small trees, generally 0.5–6 m tall, adapted to cold and arid mountain environments (Li 1996; Flora of China 2008). The stem emerges from root suckers and is consequently branched, woody, and thorny. From erect and multi-stemmed shrubs in riverine habitats (*H. rhamnoides*) to low, prostrate cushion forms in alpine zones, it exhibits varied growth patterns (*H. tibetana*). Plasticity of its structure enables it to stabilize soils, fix dunes and protect slopes (Lian *et al.* 2022).

The leaves are simple, alternate, sessile, and narrowly lanceolate (1–8 cm long), with entire margins and a thick cuticle. The upper surface is green to gray-green, while the lower surface bears silvery or brown stellate hairs that reduce water loss and reflect excess radiation an adaptation to high-altitude aridity (Flora of China 2008; Lian *et al.* 2022). The indumentum color and density, as well as leaf size, are crucial for distinguishing *H. rhamnoides*, *H. tibetana*, and *H. neurocarpa* (Liu and He 2020).

Being dioecious, *Hippophae* produces unisexual flowers on separate male and female plants (Li and Schroeder 1996; Ruan *et al.* 2015). Fertilized flowers develop into fleshy pseudo-drupes or berries measuring, orange to yellow when mature, which constitute the primary ethnobotanical, nutritional, and commercial value of sea buckthorn (Wang *et al.* 2022; Liu and He 2020).

Factors such as leaf morphology (shape, indumentum color), branch types, thorn density, and fruit size and color are the distinguishing characteristics among various species. *H. rhamnoides* and *H. tibetana* have been confirmed to be genetically distinct though closely related taxa on the basis of molecular phylogenetic analyses (Bartish *et al.* 2002; Wang *et al.* 2008).
The sea buckthorn's taxonomic characteristics are significant in ethnobotany since they have an immediate impact on its utilization, harvesting, and conservation. Sea buckthorn is a dioecious plant with considerable sexual dimorphism, with male and female plants having different morphology, physiology, and reproductive traits (Chen *et al.* 2025). Such sex-specific variations have an impact on reproductive patterns, population dynamics, and resource management (Fan *et al.* 2024). Moreover, its strong nitrogen-fixing capacity and clonal propagation help in sustainable use in mountain ecosystems and ecological restoration (Zeng *et al.* 2024).

Global Distribution

Within its global distribution range, the IHR forms a major habitat for *Hippophae* species such as *H. salicifolia* and *H. tibetana*, where these species are ecologically significant and support diverse ethnobotanical uses among Himalayan regions. The genus *Hippophae* is widely distributed across the Northern Hemisphere, reflecting its strong adaptability to temperate, cold-arid, and alpine environments (Figure 2) (GBIF 2026). it is reported survive a wide range of terrains from near sea level (~60 m) to elevations exceeding 5,000 m, spanning latitudes approximately from 35°N to 70°N (Ruan *et al.* 2021). Overall, its broad latitudinal span, wide altitudinal tolerance (60-5200m), and high edaphic adaptability establish sea buckthorn as one of the most widely distributed woody nitrogen-fixing genera in the Northern Hemisphere (Ruan *et al.* 2021; Wang *et al.* 2024).

Globally, sea buckthorn is reported from more than 50 countries, with an estimated total coverage of approximately 2.3 million hectares (Nybom *et al.* 2023). China currently is at the helm of sea buckthorn resources, accounting for nearly 90% of the total area (~2.1 million ha), largely distributed across the Loess Plateau, Qinghai–Tibetan Plateau, and Inner Mongolia, where extensive government-supported ecological restoration programs have expanded plantations by over 1.3 million ha since 2000 (Ruan *et al.* 2013; Zhao *et al.* 2023; Wang *et al.* 2024). Outside China, sea buckthorn occurs at smaller but ecologically significant scales in Mongolia (~20,000 ha), Romania (~15,000 ha), India (~14,500 ha), Russia (~6,000 ha), and Pakistan (~5,700 ha), collectively representing less than 10% of the global coverage (Nybom *et al.* 2023). Natural populations grow across approximately 60,000 ha in Europe, mainly along coastal dunes and riverbanks of the Baltic and North Sea regions, dominated by *H. rhamnoides* subsp. *rhamnoides* (Bartish *et al.* 2020).

The Himalayan region, encompassing India, Nepal, and Bhutan, supports high-altitude taxa such as *H. tibetana* and *H. salicifolia* between 900 and 4,500 m, contributing a relatively small proportion of global area but representing high ecological and genetic diversity (Singh *et al.* 2022). Beyond its native Eurasian range, *H. rhamnoides* has been intentionally introduced and naturalized in parts of North America and New Zealand, particularly on marginal and sandy soils, highlighting its suitability for land restoration in degraded environments (FAO 2023; Nybom *et al.* 2023).

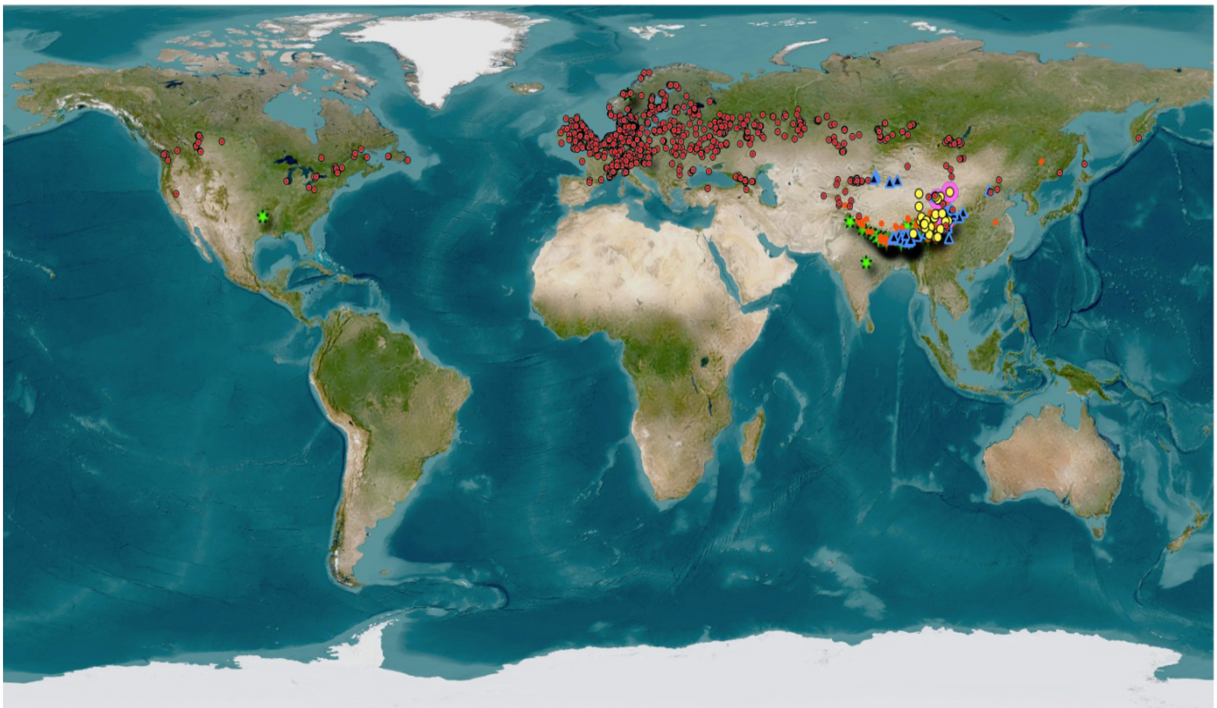

Figure 2. Global and Indian distribution of Sea buckthorn

Distribution in Indian Himalayan region

Sea buckthorn (*Hippophae rhamnoides* L. and *Hippophae salicifolia* D. Don) occurs naturally in the cold-arid and temperate regions of the Indian Himalayas, with major populations reported from Ladakh (Leh–Kargil), Lahaul and Spiti, Kinnaur, Pangi valley of Himachal Pradesh, and the Kumaon–Garhwal region of Uttarakhand covering an estimated area of 14,500 hectares (Figure 3) (GBIF 2026) (Chaudhary and Sharma 2023; Jain *et al.* 2022; Kaushik *et al.* 2025; Paul *et al.* 2025). In these regions, sea buckthorn predominantly occupies riverine corridors, floodplains, alluvial fans, and hill slopes, where it functions as a keystone species for soil stabilization, nitrogen fixation, erosion control, and microhabitat formation in fragile Himalayan ecosystems (Dhyani *et al.* 2011; Sharma *et al.* 2019; Dolma and Uniyal 2025).

Ladakh: It represents the principal repository of natural sea buckthorn resources in the country, accounting for over 64% of the total area under this species. Around 7184 ha of land is covered by pure sea buckthorn stands in Europe, while mixed sea buckthorn vegetation occupies around 2083 ha (Chauhan *et al.* 2006). *H. rhamnoides* comprises the dominant population in the region although *H. tibetana* population also exists on a small scale. The species flourishes in a wide range of soils from strongly acidic to highly saline and is highly adaptable (Singh 2004). Additionally, *H. salicifolia* populations have been recorded in the Suru Valley (Stobdan *et al.* 2017). Sea buckthorn populations are found growing along the banks of the Nubra, Shyok, and Indus Rivers, as well as in the Changthang region, where altitudes reach up to 4,700 meters (Stobdan *et al.* 2008).

Uttarakhand: Growing along riverbanks at lower elevations (1700 to 3000 meters), *Hippophae salicifolia* can be found in districts viz. Rudraprayag, Chamoli, Uttarkashi and Pithoragarh, while *Hippophae tibetana* grows at higher altitudes (3,300 to 4,500 meters) in Pithoragarh and Chamoli districts (Singh 2022). The total sea buckthorn coverage in Uttarakhand is gauged at approximately 3,750 hectares (Yadav *et al.* 2009).

Himachal Pradesh: *H. rhamnoides*, *H. salicifolia*, and *H. Tibetana* populations are found in Lahaul and Spiti and Kinnaur districts. Villages such as Sissu, Khorpani, Raling, Khongsar, Gondhla, and Dalang in the Chandra Valley (2958 mts to 3110 mts) are home to the species occurring in isolated patches. In addition, *H. rhamnoides* can be found growing along the banks of Bhaga River while villages viz. Kardang and Tinu host populations of *H. salicifolia.* As one moves towards Spiti Valley, one can witness *H. tibetana* populations growing at higher altitudes (4000 mts to 4200 mts) villages such as Losar, Takcha, Chicham and Kibbar. Preliminary assessments indicate that the total area occupied by sea buckthorn in Himachal Pradesh is approximately 1,000 hectares (Stobdan *et al.* 2011).

Sikkim: In Sikkim, sea buckthorn is commonly found on slopes and along riverbanks in the Lachen, Zema I, Zema II, Zema III, and Lachung regions (Basistha 2009), covering an estimated 300–500 hectares of forested area. The dominant species in this region is *Hippophae salicifolia*, occurring between 2,280 and 3,100 meters (Singh 2022), while small patches of *H. rhamnoides* are observed at higher elevations of 2,800–3,300 meters (Basistha 2009).

Arunachal Pradesh: In Arunachal Pradesh, sea buckthorn occurs in limited patches along the banks of the Naymjang Chu River in the Zimathang area, approximately 100 km from Tawang. Here, sea buckthorn extends along a 5 km stretch at an altitude of 2,438 meters (Vairale *et al.* 2020).

Collectively, these distribution patterns imply that *Hippophae* species have different ecological preferences across the IHR, with *H. rhamnoides* dominating cold-arid landscapes and *H. salicifolia* occurring more commonly in moist temperate regions. This regional difference emphasizes the necessity for management strategies and habitat-specific conservation (Sharma *et al.* 2019; Paul *et al.* 2025).

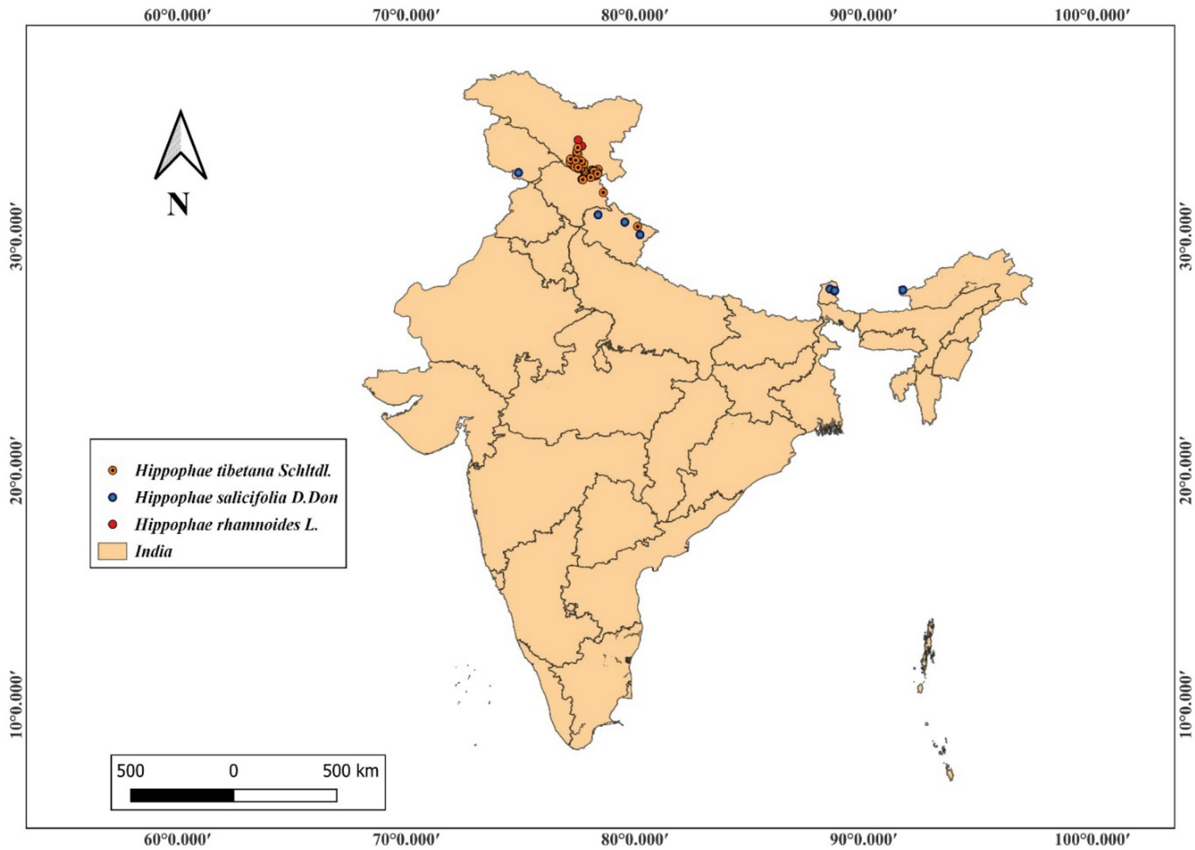

Figure 3. State wise distribution of Sea buckthorn in Indian Himalayan region

Bioactive Compounds and Active Principles

Sea buckthorn (*Hippophae* spp.) is known as a pharmacologically significant plant due to existence of a wide range of bioactive substances in its fruit pulp, seeds, berries, and leaves including flavonoids, bioactive polysaccharides, vitamins, phenolic acids, fatty acids, phytosterols, tocopherols, and carotenoids (Suryakumar and Gupta 2011; Fatima *et al.* 2012). Instead of concentrating on certain chemicals, these phytochemical groups collectively contribute to plant's recognized antioxidant, anti-inflammatory, antibacterial, hepatoprotective, cardioprotective, and tissue regenerative properties (Fatima *et al.* 2012; Gâtlan and Gutt 2021; Wang *et al.* 2022; Čulina *et al.* 2023; Hussain *et al.* 2024; Yuan *et al.* 2025).

In the IHR, especially among communities in Ladakh, Lahaul–Spiti, Kinnaur, and Uttarakhand, sea buckthorn is frequently integrated into traditional healthcare and sustainable practices (Suryakumar and Gupta, 2011; Gupta *et al.* 2011). Berries are usually harvested between late summer and early autumn and consumed fresh or processed into jams, juices, dried products, herbal drinks, and for household use (Suryakumar and Gupta, 2011; Liu *et al.* 2023). Typically, these preparations are used to support digestion, alleviate fatigue, and maintain general health. Fruit pulp and seed oil are used to apply on cracked skin, frostbite, burns, and wounds, whereas leaf-based preparations, including decoctions and infusions, used in local remedies for cough, inflammatory conditions, and digestive discomfort (Suryakumar and Gupta, 2011; Gupta *et al.* 2011). These practices demonstrate the ongoing significance of sea buckthorn within native knowledge systems and its role in sustaining traditional healthcare across Himalayan communities.

In addition to these broad bioactive compounds, several active principles have been isolated from *Hippophae rhamnoides* and are being investigated for contemporary pharmacological and nutraceutical uses (Żuchowski 2023). Flavonoids like isorhamnetin and quercetin are recognized as significant active substances because of their hepatoprotective, anti-inflammatory, and anticancer properties (Martiniakova *et al.* 2024). Sea buckthorn is a common source of palmitoleic acid, which is utilized in dermatological formulations and nutraceutical supplements to improve skin and mucosal health (Song *et al.* 2025). Phytosterols like β-sitosterol are often used in cholesterol-lowering nutraceutical products, whereas sea buckthorn polysaccharides are being looked into for their immunomodulatory and anti-tumor potential (Chen *et al.* 2024; Dong *et al.* 2025). Current study concentrates on the isolation of active compounds, advancement of standardized extracts, nano-formulations, and clinical evaluation of sea buckthorn oil and flavonoid-rich extracts, demonstrating a substantial potential for phytopharmaceutical and nutraceutical products (Gao *et al.* 2025; Yang *et al.* 2025). Table 1 summarizes the bioactive substances found in various sea buckthorn sections along with their biological roles.

The wide range of phytochemical composition and pharmacologically active compounds found in sea buckthorn emphasize its significance as a traditional medicinal herb as well as potential source of functional food ingredients, phytopharmaceuticals, and nutraceuticals (Mihal *et al.* 2023), which is consistent with the increasing interest in plant-based therapeutics in research.

Ethnobotanical Importance of Sea buckthorn in the Indian Himalayan States

Commercial uses

Cosmetics: In the Indian Himalayan region, particularly in Ladakh, Himachal Pradesh, and Uttarakhand, local communities traditionally use sea buckthorn oil to treat frostbite, cracked skin, and sunburn (Wang *et al.* 2022; Mihal *et al.* 2023; Devendran *et al.* 2025).

These practices are connected to the plant's anti-inflammatory and antimicrobial properties. In recent years, the use of sea buckthorn fruit oils and seed in cosmetics has grown (Mei *et al.* 2023). Its high linoleic acid content aids in restoring the epidermal lipid barrier, preventing trans epidermal water loss, and maintaining healthy skin (Solà Marsiñach and Cuenca 2019).

Its extracts find use in the preparation of herbal shampoos and hair conditioners that improve skin and hair health (Koskovac *et al.* 2017). Sea buckthorn-based products are increasingly being recognized for their antioxidant, UV-protection, anti-aging, and skin-repairing properties. Singh *et al.* (2025) have in their research substantiated these applications confirming the skin-shielding properties of its oils which can be attributed to the presence of palmitoleic acid (omega-7) and tocopherol-rich oil which promote epithelial regeneration, collagen synthesis, and the repair of UV-induced oxidative damage in skin tissues. Their study demonstrated that topical or oral administration of sea buckthorn oil slows down photoaging by supporting keratinocyte stability and redox balance. Furthermore, their study attributed the photoprotective and antioxidant effects of sea buckthorn to the presence of carotenoid contents. The expansion of sea buckthorn based cosmetic industry across the Indian Himalayan is proving an asset to the economy and welfare of this mountainous region.

Food Industry: Sea buckthorn finds use in the development of various functional food and nutraceutical products owing to its exceptional nutritional and medicinal properties. The fruit pulp and seeds are used to prepare juices, wines, jellies, herbal teas, jams and dairy-based formulations (Wang *et al.* 2022)., Sea buckthorn juice and beverages are produced in Ladakh, Himachal Pradesh, and Uttarakhand to boost immunity and reduce oxidative stress (Stobdan *et al.* 2017; Yadav *et al.* 2019;

Singh *et al.* 2024). Within the Himalayan region, sea buckthorn is a significant food source in high-altitude communities. Owing to its nutritional and therapeutic characteristics, sea buckthorn is processed into many food products and has substantial significant value as a food and medicinal resource (Shi *et al.* 2025; Negi *et al.* 2026). The pulp and seed oils extracted from sea buckthorn are added into health drinks and squashes (Small *et al.* 2002).

Shade-dried sea buckthorn leaves are combined with mountain herbs like mint (*Mentha longifolia*), oregano (*Origanum vulgare*), and yarrow (*Achillea* spp.), to prepare herbal teas known for their therapeutic qualities. Sea buckthorn juice residues yield a natural pigment used as a coloring and bioactive additive in food and pharmaceutical industries (Li and Beveridge 2007). Sea buckthorn powder finds application in bakery and dairy for enhancing nutritiousness, sensory qualities, and probiotic viability (Terpou *et al.* 2017; Nilova and Malyutenkova 2018; Terpou *et al.* 2019). Its resilience to cold, arid Himalayan conditions and increasing popularity as a health food have established sea buckthorn as a precious Indian Himalayan bioresource (Wang *et al.* 2022).

Environmental Benefits: Sea buckthorn plays a vital role in soil and water conservation across the Indian Himalayas, particularly in the cold desert regions of Ladakh. The species is highly valued for its ability to thrive in marginal and fragile ecosystems due to its extensive root system, drought tolerance, and resistance to salinity and low temperatures (Ruan *et al.* 2013; Sharma *et al.* 2019). Its dense root network binds soil particles effectively, preventing erosion and promoting slope stabilization, while the nitrogen-fixing symbiosis with *Frankia* enhances soil fertility (Stobdan *et al.* 2017).

Studies have shown that sea buckthorn plantations increase soil organic matter and nitrogen content compared to barren soils (Stobdan 2024). In the trans-Himalayan landscape of Ladakh, the species has been widely introduced for dune fixation and rehabilitation of degraded lands. Since the 1960s, the State Forest Department has expanded sea buckthorn plantations through root suckers, particularly in Hunder village (Nubra Valley) and more recently in Durbuk and Nyoma of the Changthang Valley. These plantations facilitate sand dunes stabilization and soil moisture conservation. Additionally, sea buckthorn is acknowledged as an environmentally friendly crop that helps preserve soil and stop land erosion (Negi *et al.* 2026).

The dead organic matter that falls off established shrubs is known to enrich soil contents and moisture holding capacity. The shrub also acts as a source of biomass in regions where vegetation is scarce. This makes sea buckthorn a valuable bioresource for cooking and heating at high-altitudes (Stobdan *et al.* 2013). Sea buckthorn groves, locally known as *Tsokshing* (“forest wood”), provide a sustainable firewood supply to monasteries in Ladakh. Sea buckthorn is traditionally used as fuel in high-altitude areas (Negi *et al.* 2026).

The species has been traditionally used for roasting barley grains and preparing *Tsampa*, the staple food of the region. Other advantages include acting as a rich source of fodder during winter months for livestock such as sheep, goats, yak and the double-humped camel (Qinxiao and Hongyan 2003; Dwivedi *et al.* 2006). In high-altitude Himalayan locations, sea buckthorn is also traditionally utilized for veterinary purposes (Negi *et al.* 2026)

Traditional uses

Traditional medicine: Sea buckthorn (*Hippophae rhamnoides* L.) is a widely recognized IHR plant, that has been used in traditional Tibetan medicine for ages (Sowa Rigpa). Its medicinal applications have been documented in the Tibetan medical classic *rGyudBzi* (Four Medical Tantras) since the 8th century. It is noteworthy that over 300 formulations derived from sea buckthorn are still used in contemporary practice. In Ladakh, sea buckthorn-based preparations are prescribed by local Amchi practitioners to treat common ailments (Figure 4).

In Himachal Pradesh, especially in Lahaul and Spiti and Kinnaur, fruits and leaf decoctions of sea buckthorn are traditionally used to treat stomach ailments, joints and muscular pain, general fatigue, and respiratory complaints, while seed and pulp oils are applied externally for wounds, burns, frostbite, and chronic skin infections (Sharma *et al.* 2019; Singh 2022; Kaler *et al.* 2024). Ethnobotanical surveys from the western Himalaya also report its use in veterinary medicine for treating livestock digestive problems and debility, and as a convalescent tonic for pack animals after long journeys (Dhyani *et al.* 2010).

In Uttarakhand, *H. salicifolia* is widely valued as a multipurpose “household remedy”: fruits and bark are used for gastric disorders, liver ailments, respiratory and inflammatory conditions, while leaf decoctions are consumed as restorative herbal teas and given to patients with weakness, anemia, and chronic fever. (Yadav *et al.* 2009; Dhyani *et al.* 2010).

In Sikkim, sea buckthorn berries and leaves are used for treating cough, cold, and digestive problems, and fruit juice is traditionally applied for dyeing wool and textiles (Basistha 2009).

In Arunachal Pradesh, limited populations along the Naymjang Chu valley, fruits and leaf extracts are used for wound healing, gastrointestinal disorders, and as general health tonics, while fruit juice is occasionally used for dyeing wool and traditional fabrics (Vairale *et al.* 2020).

Recent pharmacological studies on sea buckthorn have validated its traditional uses in treating oral and vaginal mucositis, cervical erosion, duodenal and skin ulcers, cancer, digestive dysfunction, hepatic injury, thrombosis, and musculoskeletal injuries. The abundance of bioactive compounds sea buckthorn renders it as a multipurpose medicinal species of the high-altitude regions owing to its anti-inflammatory, hepatoprotective, antioxidant, gastroprotective, and tissue-healing activities (Cakilcioglu *et al.* 2011; Zore *et al.* 2025).

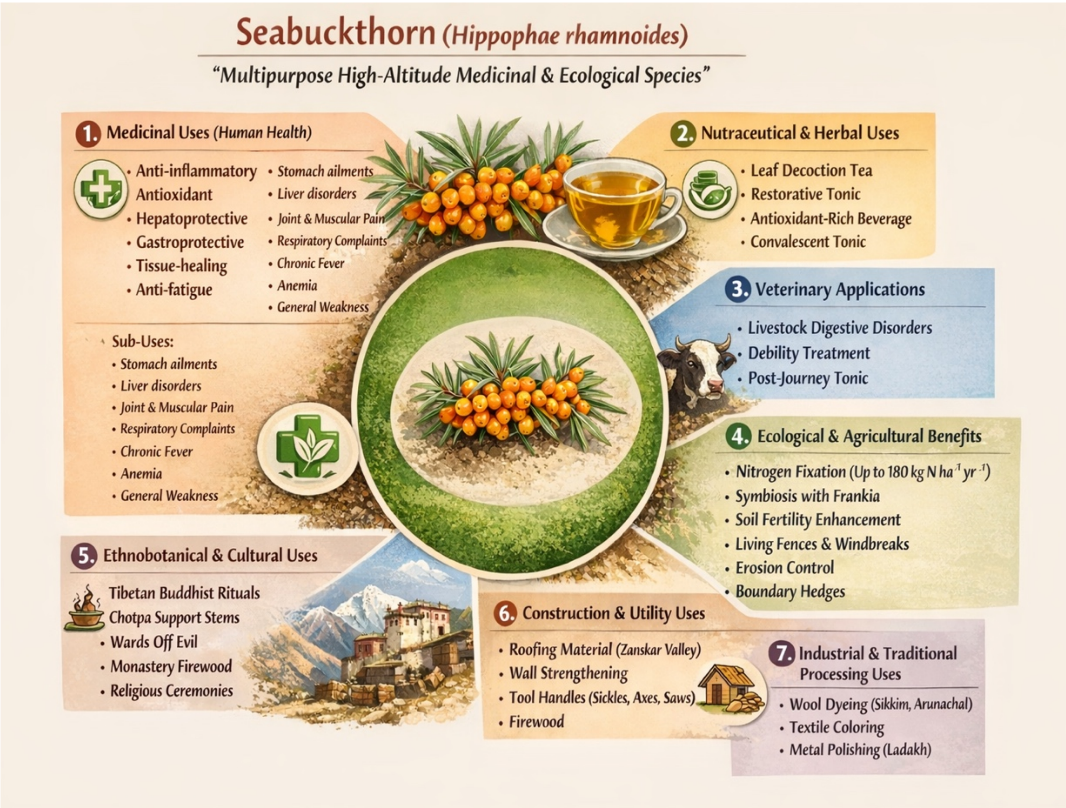

Figure 4. Ethnobotanical and medicinal uses of Sea buckthorn in Indian Himalayan region

Soil Fertility and Agricultural Applications: Sea buckthorn is traditionally cultivated around fields in the Nubra Valley, Ladakh, where soil from dense sea buckthorn patches is mixed with low-fertility soils to improve nutrient content (Stobdan *et al.* 2013). The shrub's root nodules harbor a symbiotic association with Frankia, a nitrogen-fixing bacterium, allowing fixation of up to 180 kg N ha^{-1} yr^{-1} and enhancing soil fertility (Jike and Xiaoming 1992). Similar practices of using sea buckthorn as living fences and boundary hedges to protect crops from grazing and wind damage are reported from Himachal Pradesh and Uttarakhand (Dhyani *et al.* 2010; Sharma *et al.* 2019). It's dense and thorny growth also serves as living fencing, protecting crops and plantations from stray animals and pedestrian traffic, a practice still prevalent though gradually declining due to alternative fencing materials.

Firewood and Charcoal: In the cold deserts of Ladakh, sea buckthorn provides a fast-growing source of firewood. A six-year plantation on one hectare can yield 18 t of firewood, equivalent to approximately 12.6 t of standard coal (Rongsen 1992). The wood is harvested every 3–5 years, reducing pressure on other native species such as willow, poplar, and juniper. Firewood from sea buckthorn is widely used in monasteries, for cooking, and during religious ceremonies, particularly for preparing *Tsampa*. Blacksmiths in the region prefer charcoal from sea buckthorn branches due to its high calorific value and low ash production.

Construction, Fencing, and Tree Guards: The sturdy mature stems of sea buckthorn find application in the Zanskar Valley as an excellent roofing, wall strengthening and fencing material to ward off animals and heavy snow. Additionally, the thorny branches are uses to guard young plants thereby ensuring their survival during early stages of plantation (Stobdan 2024).

Soil and Moisture Conservation: Sea buckthorn's extensive root system, reaching up to 5.37 m horizontally and 1.27 m vertically in mature shrubs, effectively binds soil and mitigates erosion. Traditional plantation of sea buckthorn along irrigation channels, riverbanks, and degraded slopes in Ladakh and Lahaul and Spiti has long been practiced stabilizing fragile soils and improve agricultural productivity (Dwivedi *et al.* 2006; Sharma *et al.* 2019).

Temporary Bridge Formation: Historically, in Ladakh, cut sea buckthorn shrubs were used to create temporary ice bridges over rivers by supporting floating ice blocks, though this practice is now largely forgotten.

Religious and Cultural Uses: Sea buckthorn stems are integral to Tibetan Buddhist rituals, serving as supports for ritual cakes (*Chotpa*) and believed to ward off evil when placed near entrances.

Agricultural Implements: Hard stems are also used as handles for traditional tools such as sickles, axes, and saws across Himalayan villages (Stobdan 2024).

Food, Nutritional, and Dye Uses: Sea buckthorn berries provide nutritional supplements, particularly in high-altitude regions. While highly acidic, ripe berries from select plants are occasionally consumed by children, and leaves are brewed as antioxidant-rich tea, though its use is declining. Sea buckthorn juice is traditionally used for dyeing wool in Sikkim and Arunachal Pradesh (Basistha 2009; Vairale *et al.* 2020). In Ladakh, fruit juice is applied for polishing metals (Rongsen 1992).

Sea buckthorn serves multiple ecological, agricultural, nutritional, and cultural purposes in the Indian Himalayas, from soil enrichment and firewood production to ritual and domestic uses, reflecting its enduring socio-ecological significance in high-altitude regions.

Comparison between Himalayan states indicates that the relative importance of sea buckthorn varies and it depends on local ecological conditions and subsistence needs. Domestic and medicinal uses are commonly documented from the central and eastern Himalayas, but ecological and fuelwood uses predominate in the Trans-Himalayan region (Dhyani *et al.* 2010; Sharma *et al.* 2019).

Nutritional and Therapeutic Potential

Expanding on the previously mentioned phytochemical makeup, sea buckthorn possesses nutritional and medicinal potential because of the synergistic action of its bioactive constituents. The fruit helps in lowering plasma cholesterol levels owing to the presence of phytosterols (4–20 times higher than soybean oil). Oils extracted from its seeds are rich in omega-3 and omega-6 fatty acids (1:1 ratio), while the berries contain a rare monounsaturated fatty acid known as palmitoleic acid (omega-7). Additionally, the presence of oleic acid renders it beneficial for the treatment of cardiovascular and metabolic disorders (Marsiñach and Cuenca 2019; Ahani *et al.* 2022).

Sea buckthorn is particularly rich in micronutrients. In addition, it is rich in macronutrients such as calcium, selenium, potassium, and magnesium, making it highly valuable for addressing nutritional deficiencies prevalent in high-altitude Himalayan communities.

In addition to its well-recognized anticancer, anti-inflammatory, cardiometabolic, and dermatological applications, recent studies have also reported anti-osteoporotic, anti-fatigue, neuroprotective, and hepatoprotective effects of *Hippophae*. These findings further support its broad therapeutic potential and reinforce its growing importance in phytomedicine and nutraceutical research (Kopčeková et al. 2023; An *et al.* 2023; Lan *et al.* 2023; Ma *et al.* 2023).

Traditional medical systems, including Tibetan, Mongolian, Chinese, and Ayurvedic literature, document the long-standing medicinal use of sea buckthorn. Ancient texts such as the *rGyudBzi* describe its therapeutic applications. Its flowers act as skin softeners (Barnaulov *et al.* 1988), while berry oil has been used for liver disorders, chronic wounds, and thrombosis (Bazaron and Chibikova 1978; Chopik *et al.* 1983; Yang *et al.* 2000; Cheng *et al.* 2003). Leaves and branches are reported for treating diarrhoea and rheumatoid arthritis (Vereschhagin *et al.* 1959; Tsybikova *et al.* 1983), and fruits for pulmonary, cardiac, and metabolic disorders (Bezaron and Aseeva 1984; Badareva 1985; Cakilcioglu *et al.* 2011).

Table 1. Bioactive compounds actively present in different parts of sea buckthorn

Plant part	Bioactive compound	Chemical class	Structural type/formula	Functions	References
Leaves	Isorhamnetin	Flavonoid	Flavonol/ ($C_{16}H_{12}O_7$)	Antioxidant, anti-inflammatory, anticancer	Yuan *et al.* (2025)
Leaves	Quercetin	Flavonoid	Flavonol/ ($C_{16}H_{12}O_7$)	Antioxidant, anti-inflammatory	Wang *et al.* 2022)
Leaves	Kaempferol	Flavonoid	Flavonol/ ($C_{15}H_{10}O_6$)	Antioxidant, anticancer	Čulina *et al.* (2023); Hussain *et al.* (2024)
Leaves	Rutin	Flavonoid	Flavonol/ ($C_{16}H_{12}O_7$)	Anti-inflammatory, vascular protection	Ganeshpurkar and Saluja (2017); Jaśniewsk and Diowksz (2021)
Berries	Lutein	Carotenoid	Oxygenated carotenoid/ ($C_{40}H_{56}O_2$)	Skin and Eye protection, antioxidant	Gherasim *et al.* (2024); Wojdyło *et al.* (2026)
Berries	Polysaccharides	Carbohydrate	Glucose polymer	Immunomodulatory	Lan *et al.* (2023); Yoon *et al.* (2024)
Leaves	Phenolic acids	Phenolics	Hydroxybenzoic acids and Hydroxycinnamic acids	Antioxidant, antimicrobial	Kumar and Goel (2019); Singh *et al.* (2024)
Berries	Isorhamnetin	Flavonoid	Flavonol/ ($C_{16}H_{12}O_7$)	Antioxidant, anti-inflammatory, anticancer	Gong *et al.* (2020)
Berries	Quercetin	Flavonoid	Flavonol/ ($C_{16}H_{12}O_7$)	Antioxidant, anti-inflammatory	Raal *et al.* (2023)
Berries	Ascorbic acid	Vitamin C	Six Carbon Lactone structure/ (C6H8O6)	Antioxidant	Akbari *et al.* (2016); Wang *et al.* (2022)
Berries	β-carotene	Carotenoid	Cyclic carotenoid tetraterpenoid/ (C40H56)	Anti-inflammatory, vascular protection	Criste *et al.* (2020); Lara-Abia *et al.* (2021)
Berries	Lycopene	Carotenoid	Linear carotenoid tetraterpenoid/ (C40H56)	antioxidant	Milani *et al.* (2017); Mihal *et al.* (2023)
Berries	Zeaxanthin	Carotenoid	Xanthophyll carotenoid	Eye health	Visan *et al.* (2023; Gherasim *et al.* (2024)
Pulp oil	Palmitoleic acid	Fatty acid	Monounsaturated fatty acid/ (C16H30O2)	Skin repair, wound healing	Fatima *et al.* (2012)
Seed oil	Linoleic acid	Fatty acid	Polyunsaturated fatty acid/ (C18H32O2)	Cardiovascular health, Anti-inflammatory	Fatima *et al.* (2012)
Seed oil	β-sitosterol	Phytosterol	Steroid structure	Cholesterol lowering	Fatima *et al.* (2012)
Berries, Seed oil	Tocopherol	Vitamin E	Chromanol ring structure	Antioxidant	Gâtlan and Gutt, (2021)

A recent study by Singh *et al.* (2025) highlights sea buckthorn as a “golden superfruit” due to its biochemical richness. The presence of polysaccharides contributes to dietary fiber content, supporting gut microbiota and glucose regulation. Essential amino acids such as leucine, methionine, and threonine contribute to metabolic and cognitive functions, while fatty acids (omega-3, 6, 7, and 9) support cardiovascular health.

Studies have reported beneficial effects on cardiovascular and metabolic health. Sea buckthorn puree has been associated with reductions in diastolic blood pressure, and seed oil has been linked with improved blood pressure in high-altitude populations (Vashishtha *et al.* 2017; Zhou *et al.,*2022). Improvements in lipid profiles, including reductions in total cholesterol, triglycerides, and LDL cholesterol, have also been reported (Stobdan 2024).

A clinical study by Gao *et al.* (2014) reported that NAFLD patients administered sea buckthorn capsules (1.5 g, three times daily for 90 days) showed significant reductions in LDL cholesterol and serum alanine aminotransferase, along with improved liver function. Similarly, a human-based study by Xiao *et al.* (2013) reported improved digestion and overall development in dyspeptic children following sea buckthorn-based emulsion intake.

Evidence from both experimental and human studies supports its role in wound healing and skin health. Sea buckthorn-based ointment has been reported to accelerate healing of second-degree burns compared to silver sulfadiazine (Shafiee *et al.* 2021). Clinical evidence also suggests that sea buckthorn oil improves vaginal mucosal integrity in postmenopausal women (Larmo *et al.* 2014). Oils derived from seeds and pulp have also been reported to reduce melanin levels in hyperpigmentation conditions (Yang *et al.* 1999; Khan *et al.* 2013).

Studies further indicate benefits in metabolic and systemic conditions. Supplementation has been associated with improvements in lipid profiles, BMI, adipokines, and inflammatory markers in obese adolescents (Shivakumar *et al.* 2015). Human studies have also reported reduced platelet aggregation (Johansson *et al.* 2000) and improvement in dry eye syndrome (Larmo *et al.* 2010).

Sea buckthorn also has applications in veterinary medicine. Experimental studies have shown that ointments containing sea buckthorn fruit powder are effective in healing infected wounds (Mahajan *et al.* 2006). Similarly, animal-based experimental research reported that sea buckthorn seed oil was effective in treating gastric ulcerations in dogs, showing better results than conventional drugs (Dogra *et al.* 2013).

Overall, the available literature indicates that while substantial evidence from experimental studies supports the pharmacological potential of sea buckthorn, clinical evidence in humans, although promising, remains comparatively limited and requires further large-scale validation.

All things considered, the information that is currently available consistently supports the diverse health-promoting properties of sea buckthorn. However, the majority of results are derived from experimental research, underscoring the necessity of more well-designed human clinical trials (Wang *et al.* 2022; Kopčeková *et al.* 2023).

Conservation Challenges and Recent Works

In recent years, institutional and regional development efforts have increasingly focused on enhancing scientific understanding, cultivation, and sustainable utilization of sea buckthorn (*Hippophae rhamnoides* L.) in the Indian Himalayan Region. In Ladakh, a Centre of Excellence for Sea Buckthorn has been established as part of broader regional development plans to boost rural economies and create structured platforms for scientific farming, processing technology, and value-chain enhancement. This initiative represents significant in situ-linked conservation efforts, as it promotes cultivation-based pressure reduction on natural populations while strengthening local livelihood systems (Administration of Union Territory of Ladakh 2025).

Complementing this, research institutions such as the Govind Ballabh Pant National Institute of Himalayan Environment (GBPIHED 2025) are running programs through their regional centers that engage in biodiversity monitoring, community-linked ecological research, and socio-economic development work associated with Himalayan plants. These initiatives largely reflect in situ conservation approaches, particularly through habitat monitoring, community participation, and landscape-level ecological management. Projects in Lahaul and Spiti further focus on value addition and entrepreneurship development using sea buckthorn, indirectly supporting conservation by reducing unsustainable extraction from wild populations (GBPIHED 2025).

In contrast, several studies and institutional efforts emphasize ex situ conservation strategies, particularly in the context of genetic resource management and propagation. At the Department of Tree Improvement and Genetic Resources, Dr Y.S. Parmar University of Horticulture and Forestry, Nauni (Solan), a long-term project funded by PPVandFRA focuses on gene bank establishment, germplasm characterization, and DUS validation, representing a structured ex situ conservation approach aimed at preserving genetic diversity and supporting breeding programs. Similarly, earlier studies by Raina *et al.* (2012) and Jain *et al.* (2022) have focused on germplasm collection and characterization and developed propagation techniques such as tissue culture and vegetative multiplication, facilitating large-scale plantation and restoration programs.

Despite these in situ and ex situ conservation efforts, real-field conditions indicate persistent and intensifying threats to natural populations. Habitat fragmentation driven by road construction, strategic infrastructure development, and riverbank modification continues to reduce and isolate natural stands in the Trans-Himalayan region (Chettri *et al.* 2018; Paul *et al.* 2025). Field-level evidence further shows that overexploitation for fuelwood, fodder, fencing, and fruit harvesting significantly disrupts regeneration dynamics, particularly in areas lacking regulatory control (Stobdan *et al.* 2017).

Natural *Hippophae* populations in IHR are under increasing pressure from human usage and habitat sensitivity, particularly in the Trans-Himalayan cold deserts of Ladakh, Lahaul-Spiti, and Kinnaur (Pandey, 2025; Stobdan *et al.* 2017; Paul *et al.* 2025). This is an increased issue because sea buckthorn in India is frequently found near river bottoms, irrigation channels, and small streams creating numerous stands that are closely tied to small riparian areas (Singh, 2018). Reviews of Ladakh sea buckthorn warn that unchecked use can result in loss of diversity and potentially local extinction danger if wild genotypes are not protected. Wild populations are currently being used for economic benefits with minimal plantation efforts (Kalia *et al.* 2011; Lamo *et al.* 2019).

The well-documented anthropogenic danger is extraction pressure. Sea buckthorn is utilized in Ladakh for construction materials, tree guards, fuelwood, fencing, and agricultural tools in addition to berries (Stobdan *et al.* 2013). The average amount of sea buckthorn fuelwood collected by households in Nubra Valley was approximately 930kg annually, and berry processing produced 464.25 metric tons of pulp annually, demonstrating a significant reliance on the species for both sustenance and income (Dolma and Uniyal, 2025). Since 2001, gathering berries from their natural habitat has been a significant regional activity. The demand already outpaces the capability of the region's supply, supporting description of the current harvest pressure as high (Stobdan *et al.* 2017). The literature also supports concerns regarding grazing-related recruitment limitations; however, they should be phrased carefully. Studies on alpine grazing and general restoration demonstrate that grazing's impacts on recruitment are context-dependent rather than always detrimental (Fang et al. 2024; Durbecq et al. 2021; Sun et al. 2020). Nevertheless, these studies also demonstrate that grazing can affect recruitment and that, in situations when vegetation is damaged, exclusion or controlled grazing may be employed (Fang et al. 2024; Durbecq et al. 2021; Sun et al. 2020). Additionally, uncontrolled grazing pressure in alpine and cold desert ecosystems damages young seedlings and restricts natural recruitment, while climate variability further influences population stability and fragmentation.

According to recent research, Himalayan plant species' suitable habitats are predicted to undergo major elevation shifts due to climate change, with populations increasingly migrating up higher elevations in search of climatically acceptable refugia (Ali *et al.* 2026). According to Ali et al. (2026), these changes are also linked to decreased landscape connectivity and increasing habitat fragmentation, which may have a negative impact on Himalayan plant species' population persistence and regeneration (Ali *et al.* 2026).

Together, these results show that the reduction of natural *Hippophae* populations is caused by a number of interrelated pressures rather than a single hazard, highlighting the necessity of integrated conservation strategies.

Overall, the literature indicates that while in situ approaches are crucial for maintaining ecological processes and natural regeneration, ex situ strategies play a complementary role in genetic conservation and restoration. However, the lack of effective integration between these approaches at the field level remains a critical gap, necessitating coordinated conservation planning, sustainable harvesting regulations, and stronger community participation frameworks. Other Himalayan locations have also identified similar conservation difficulties and the necessity of preserving ethnobotanical knowledge through sustainable management (Ullah et al. 2024; Ullah, 2025).

Limitations of Existing Research and Comparative Insights

Although sea buckthorn (*Hippophae* spp.) has been extensively researched for its ethnobotanical, nutritional, medicinal, and ecological properties, a critical assessment of the current literature identifies several limitations and research gaps that require attention in future studies. The majority of research on sea buckthorn is mostly concerned with phytochemical composition, traditional uses, and antioxidant activity, although very few research have looked into pharmacokinetics, standardization of extracts, clinical efficacy, and long-term therapeutic safety in humans. In vitro experiments or animal models serve as the foundation for the majority of pharmacological research, and well-designed clinical trials are still limited, which limits the applicability of experimental results into clinical applications. Furthermore, because phytochemical composition varies with plant part, species, altitude, climatic conditions, and extraction procedures. This methodological diversity emphasizes the necessity for uniform experimental protocols and adds to variations in reported biological activities (Suryakumar and Gupta, 2011; Wang *et al.* 2022).

A further limitation in existing research is the lack of comparative studies among different *Hippophae* species and populations in various geographical areas. Sea buckthorn growing under various environmental conditions such as Himachal Pradesh, Ladakh, Uttarakhand, and Sikkim may exhibit different phytochemical composition, oil content, and medicinal properties because of variation in altitude, climate, and soil conditions. However, there are currently few systematic comparative studies assessing genetic diversity, phytochemical variability, pharmacological efficacy. These comparison analyses are crucial for identifying high-value chemotypes and selecting appropriate planting material for nutraceutical and medical uses.

Furthermore, many studies focus on individual aspects such as distribution, phytochemistry, ethnobotany, or ecological restoration, however comprehensive research linking traditional knowledge, pharmacology, phytochemistry, conservation strategies, and clinical evidence are limited. Additionally, only few studies have been done on sustainable harvesting practices, climate change impacts, regeneration ecology, and long-term sea buckthorn population monitoring in the Indian Himalayan Region. These restrictions extend beyond scholarly research because they also impede the creation of standardized phytomedicinal and nutraceutical products as well as evidence-based conservation strategy. In the Himalayan region, closing these gaps would enhance sea buckthorn's translational potential as well as sustainable resource management.

Thus, future studies should focus on characterization and isolation of active compounds, clinical trials, development of standardized extracts, climate change impact assessment, pharmacokinetic studies, conservation genetics, development of sustainable methods for cultivation and harvesting. In order to establish sea buckthorn as a sustainable nutraceutical and phytomedicinal resource while preserving the natural populations in the Indian Himalayan region, it will be crucial to integrate ecological research with pharmacological and phytochemical studies.

Conclusion

Sea buckthorn (*Hippophae* spp.) is a keystone socio-ecological species of the IHR. Its multifarious applications extend far beyond its role as a nutritionally rich "superfruit." The analysis and synthesis of information related to its distribution, traditional knowledge, phytochemistry, ecological role, and conservation reveals the crucial role sea buckthorn can play in restoring the degrading Himalayan landscapes through soil stabilization, biological nitrogen fixation, erosion control, microclimate regulation, and biodiversity support. At the same time, its fruits, seeds, and leaves serve both as traditional food and medicine across Ladakh, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh, has been validated by several recent studies that have confirmed its antioxidant, cardioprotective, hepatoprotective, dermato-protective, and metabolic health benefits.

This review concludes that Indian Himalayan populations particularly across the Trans-Himalayan ecosystems are locally vulnerable due to habitat fragmentation, climate-driven shifts in suitability, regeneration failure, unregulated harvesting, pest and disease pressures, erosion of indigenous knowledge, and weak institutional coordination. Specifically, long-term population monitoring across altitudinal gradients, conservation of wild germplasm through nurseries and molecular tools for sex determination, and sex tolerance protection and restoration of riverine and cold-arid habitats, and control of harvesting and grazing in vulnerable stands should be the top priorities of future conservation efforts.

From a phytomedicinal perspective, sea buckthorn represents a significant plant species having considerable potential for the advancement of phytopharmaceuticals, nutraceuticals, and functional food products. The presence of bioactive and pharmacologically active compounds such as flavonoids, fatty acids, phytosterols, carotenoids, and polysaccharides provides a strong scientific foundation for its medicinal applications.

The most important goals, however, are standardization of extracts of active chemicals, pharmacokinetic and safety investigations, and well-designed human clinical trials to confirm therapeutic claims because phytochemical and preclinical research continue to dominate existing data.

Strategies that are integrated, region-specific, and climate-resilient should direct future research and management. Monitoring natural populations across elevation gradients, establishing certified nurseries and wild germplasm conservation programs, combining species distribution models with field-based restoration to identify safe habitats, strengthening community-based sustainable harvesting frameworks, and enhancing policy coordination linking conservation, livelihood, and value addition are some of the priority actions. Concurrently, the documenting the use of traditional knowledge should adhere to the principles of ethical access and benefit sharing, including, where appropriate, conformity with the Nagoya Protocol. When taken as a whole, these actions establish sea buckthorn as a useful flagship plant for ecological stability, sustainable livelihoods, and climate-resilient restoration in the Indian Himalayas.

Declarations

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