Chapter

Effect of Climate Change on Conifer Plant Species, *Juniperus procera*, and *Podocarpus falcatus*, in the Case of Ethiopia: Critical Review Using Time Series Data

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Abstract

The *Juniperus procera and Podocarpus falcatus* tree species are the only indigenous conifer plants that Ethiopia has and dominantly found in dry Afromontane forests of the country. However, dry Afromontane forests are threatened by climate change. The objective of this study is to analyze the effect of climate change on the regeneration and dominance of the *J. procera and P. falcatus* tree species in Ethiopia. The regeneration status classes and importance value index score classes analysis was done along the time series. This study revealed that *J. procera* had a fair regeneration status, while *P. falcatus* exhibited an alternate regeneration status between fair and good. Not regenerating regeneration status was recorded in 2006–2010 and 2016–2020 time series for *J. procera*, while in 2011–2015 and 2021–2023 for *P. falcatus.* Regarding the importance value index score of the species, *J. procera* had the top three throughout the all-time series except in 2011–2015 which had the lowest importance value index score, whereas *P. falcatus* had the top three importance value index score status from 2016 to 2023 time series. Safeguarding these conifer species from the negative effects of climate change relies on the attention of all responsible bodies.

Keywords: *Juniperus procera*, *Podocarpus falcatus*, sustainability, regeneration status, importance value index

1. Introduction

Conifer plants are woody plants that have simple leaves, simple pollen cones, and compound or reduced ovulate cones grouped in gymnosperms. Conifer plant species are found dominantly in the major terrestrial landscapes. However, conifers have less species diversity which accounts for less than 0.3% of the species diversity from the earth's plant species [1]. Ethiopia has eight natural vegetation types based on elevation

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and climate gradients. From these vegetation types, the dry Afromontane and grassland complex is found in the majority of Ethiopian parts along altitudinal gradients of 1500–3000 m.a.s.l. This forest type is considered as coniferous forest [2, 3] because the warm highland part of dry Afromontane forests with 1500 to 2500 m.a.s.l of altitude range dominated by the only two co-occurring species in the country, namely *Juniperus procera* and *Podocarpus falcatus* [4, 5]. Similarly, different scholars indicated that the dry Afromontane forest of Ethiopia is a coniferous forest. For example, the dry Afromontane coniferous forest of Dodola in the Bale Mountains [6] dominantly harbor *J. procera* and *P. falcatus* [3].

On the other hand, climate change is a common environmental problem worldwide and in Ethiopia too. For example, 19 and 3% of the country's total area experienced significant decreasing and increasing trends of rainfall, respectively from 1901 to 2020 [7]. There is also a significant mean temperature increment trend over 120 years spatially and temporally ranged from 0.24 to 1.92°C and from 0.72 to 1.08°C, respectively in Ethiopia [7]. Similarly, climate change, mean maximum and minimum temperature, has increased by 0.047 and 0.028°C/year, respectively, for the period 1983–2014 in Ethiopia. However, the total rainfall has declined by 10.16 mm per annum whereas, the rainfall has declined by 2.198, 4.541, 1.814, and 1.608 mm per annum for Ethiopian summer, spring, autumn, and winter seasons respectively [8]. A slight increase in average temperature with an insignificant trend but a significant trend in minimum temperature is documented, while a decreasing trend of rainfall is documented in dry Afromontane forest fragments in northern Ethiopia [9].

Consequently, the dry Afromontane forest is highly sensitive to climate change in combination with other factors. For example, [10] revealed that a combination of climate, topographic factors, and local human disturbance controlled the stability of dry Afromontane forests. Furthermore, the dry Afromontane conifer forest, as well as the rest of the forest of the country, is at risk due to the expansion of agricultural land as a result of population pressure. For instance, [11] states that the pollen data indicated increased anthropogenic activity such as deforestation and agriculture during the last millennium in Ethiopia. Similarly, evergreen dry Afromontane forest patches in Amhara National Regional State of Ethiopia are influenced by severe anthropogenic disturbances [12]. Furthermore, [13] indicates that there is a high level of anthropogenic activities in the Bale Mountains National Park. Climate, population growth, and anthropogenic factors are the main factors that could affect montane forest ecosystems in Kenya [14]. Similarly, [15] states that climate greatly modifies the composition, structure, productivity, disturbance regimes, water production, and nutrient retention. According to combined data of plant-wax δD and δ13C values with pollen, Ethiopian highlands' vegetation is sensitive to precipitation changes [11].

However, the impact of climate change on regeneration and the dominance of coniferous species of dry Afromontane forest of Ethiopia has not been explored and reported in a detailed and holistic manner. For example, there are few studies on assessing the impact of climate change on the forest ecosystem of Ethiopia [15]. Therefore, the impact of climate change on coniferous species of dry Afromontane forest of Ethiopia namely *J. procera* and *P. facaltus* species are evaluated from the perspectives of the regeneration and dominance status along time series, and the predicted impact of climate change on their future spatial distribution. Therefore, this chapter provides a better understanding of the effect of climate change on the coniferous species of dry Afromontane forests that allows urgent and sustainable adaptation actions to enhance resilience.

2. Methodology

The data sources of this chapter were peer-reviewed published papers. The articles were searched by Google Scholar using sentences such as "impacts of climate change on the dry Afromontane forest of Ethiopia" and "climate change impact on *J. procera* and *P. falcatus* in Ethiopia." The names of each species were used separately in the searching process. Keywords such as dry Afromontane, structure, regeneration, and Ethiopia were also used in searching for the status of dry Afromontane forests in Ethiopia. Generally, 152 articles were downloaded and from these 102 were used for this work. The collected data were organized and analyzed in time series accordingly following scientific standards. Time series data are the genuine way to understand the change in ecological processes of terrestrial and aquatic ecosystems in ecology [16, 17]. Therefore, in this study time series data were used to understand the effect of climate change on the regeneration and dominancy in coniferous species of Ethiopia where the dominance of the species is analyzed from the importance value index (IVI) [18] score of the species in the forest.

Data were analyzed across time series 1996–2023 for regeneration data and 2006–2023 for IVI data. The time series was fixed based on the availability of published documents on the coniferous species of Ethiopia. The time series were classified as presented here below. Time series for regeneration data: 1996–2000, 2001–2005, 2006–2010, 2011–2015, 2016–2020, 2021–2023. Time series for IVI data: 2006–2010, 2011–2015, 2016–2020, 2021–2023. The regeneration status of a species is the potential/capacity for renewal of species in the forest community [19, 20]. The regeneration status classes were good, fair, poor, and not regenerating. The regeneration status was defined and analyzed by comparing the density of seedlings and saplings with the density of mature trees as follows [21]. Good regeneration, if the seedling is greater than the sapling and mature tree/adult (seedling > sapling > mature tree/adult). Fair regeneration, if seedling > or ≤ sapling ≤ mature tree. Poor regeneration occurs if a species survives only in the mature and sapling stages but does not have seedlings. Not regenerating, if a species is present only in an adult form. However, IVI is the sum of the species' relative density, relative frequency, and relative dominance used to describe and compare the dominance of a species in the whole plot [18]. Where relative density is the density of a particular species in relation to the total density of all species [18]. Relative frequency is the frequency of a certain species expressed as a percentage of the sum of frequency values for all species existing [18]. Relative dominance is the basal area of a given species stated as a percentage of the total basal area of all species present [18]. The species with the highest IV index score is considered the most important in a plot and this index is used to determine the general importance of each species in the community structure. The IVI score classes were the top three, the top five, the top ten, the middle, and the lowest. The regeneration status and the IVI status of the species data were analyzed using percentiles, and the results were presented using bar graphs and tables.

3. The distribution and status of conifer plant species in Ethiopia

3.1 Species descriptions

J. procera is the only juniper that grows naturally in both the northern and southern hemispheres while, all other *Juniperus* species are confined to the northern hemisphere. *J. procera* is native to the mountainous regions and highlands of Sudan, Eritrea, and Ethiopia southward through East Africa and eastern DR Congo to Malawi and Zimbabwe and also in Saudi Arabia/Yemen [22, 23]. *J. procera* found in East Africa occurs most commonly with an altitudinal range between 1800 and 2700 m, where the rainfall averages 1000–1200 mm annually. It occurs abundantly in western Kenya and in the Ethiopian highlands [24]. *J. procera*, a dioecious species with distinct male and female cones, is an afro-montane tree often reaching 30–35 m high, and can reach 50 m maximum of the largest tree of its genus. *J. procera* is a major component of the forest that is transitional between dry, single-dominant afro-montane forest and semi-evergreen bushland and thicket. *J. procera* will not regenerate in mature forests, but is replaced by *Podocarpus* forests and similar forest types (**Figure 1**) [25].

P. falcatus specie's family *Podocarpaceae* is the second largest among conifer families with incredible diversity and functional traits, and it is the dominant southern hemisphere conifer family. Furthermore, the species *P. falcatus* synonym with *Afrocarpus gracilior* is native to Ethiopia, Kenya, Tanzania, Congo, Rwanda, South Sudan, and Uganda [26]. *P. falcatus* species is naturally growing up to 45 m high and 250 cm in diameter in 11 out of the 14 floral regions recognized in Ethiopia [27]. This tree was found predominantly in undifferentiated Afromontane forests with an altitude range of 1550–2800 m, a mean annual temperature of 13–20° C, a mean annual rainfall of 1200–1800 mm, and humus-rich sandy soils [27, 28]. *P. falcatus* is a dioecious species and is a wind-pollinated species (**Figure 2**) [28].

3.2 The distribution of conifer plant species in Ethiopia

J. procera and *P. falcatus*, plant species, are found in the dry Afromontne forest of Ethiopia predominantly and rarely in the moist montane forest (**Tables 1** and **2**, **Figure 3**). This is due to the warm highlands ("Woina Dega") zone of dry Afromontne forest in the altitude ranges of 1500 to 2500 m.a.s.l, temperatures of 15 to 20°C and rainfall ranges between 800 and 2400 mm is characterized by the occurrence of the only two conifers in the country. The cold and dry parts of these highlands are dominated by *J. procera*, while the moist and humid parts support *P. falcatus* [5]. Similarly, the tree density of *P. falcatus* increased with

Figure 1.
J. procera *specie. 1. Matured tree of* J. procera *from St. Gebriel Church, Fiche, Ethiopia. 2. Sapling of* J. procera *from Salale University (General Tadesse Biru Campus), Fiche, Ethiopia.*

Figure 2.
P. falcatus *specie. 3. Matured tree of* P. falcatus *from Salale University (General Tadesse Biru Campus), Fiche, Ethiopia. 4. Sapling of* P. falcatus *from Salale University (General Tadesse Biru Campus), Fiche, Ethiopia.*

No	Time series	IVI score	Status	Forest name	Vegetation type	Sources
1	2006–2010	82.04	2nd	Adelle forest	Dry Afromontane forest	[29]
2	2006–2010	23.66	top five	Boditi forest	Dry Afromontane forest	[29]
3	2006–2010	53.16	1st	Hugumbirda-Gratkhassu national forest priority area	—	[30]
4	2011–2015	32.5	1st	Menagesha Amba Mariam forest	Dry Afromontane forest	[31]
5	2011–2015	0.43	the lowest	Gedo forest	Dry Afromontane forest	[32]
6	2011–2015	1.61	the lowest	Tara Gedam forests	—	[33]
7	2011–2015	68.42	1st	Boda forest	Dry Afromontane forest	[34]
8	2011–2015	1.01	the lowest	Gendo forest	Moist evergreen montane forest	[35]
9	2016–2020	125.66	1st	Yerer mountain forest	Dry Afromontane forest	[36]
10	2016–2020	52.86	in the middle	Kumuli forest	Dry Afromontane forest	[37]
11	2016–2020	26.51	1st	Chilimo forest	Dry Afromontane forest	[38]
12	2016–2020	93.52	1st	Arero forest	Dry Afromontane forest	[39]
13	2016–2020	34.15	2nd	Ades forest (Southeastern Ethiopia)	Dry Afromontane forest	[40]
14	2016–2020	16.98	3rd	Yegof forest	Dry Afromontane forest	[41]
15	2016–2020	46.5	1st	Chilimo Gaji forest	Dry Afromontane forest	[42]
16	2016–2020	81.45	1st	Debre Libanos church forests	Dry Afromontane forest	[43]
17	2016–2020	12.2	top ten	Awi Zone of forests	Dry Afromontane forest	[44]
18	2016–2020	67.9	1st	Hugumburda forest	Dry Afromontane forest	[45]
19	2016–2020	0	the lowest	Gelawoldie community forest	Dry Afromontane forest	[48]
20	2016–2020	16.984	3rd	Yegof forest	Dry Afromontane forest	[41]
21	2016–2020	36.2	2nd	Ades forest (West Hararghe Zone1	Dry Afromontane forest	[47]

No	Time series	IVI score	Status	Forest name	Vegetation type	Sources
22	2016–2020	0.179	the lowest	Amoro forest	Dry Afromontane forest	[48]
23	2016–2020	36.9	2nd	Gatira George's forest	Dry Afromontane forest	[49]
24	2016–2020	1.992	the lowest	Gemechis forest	Dry Afromontane forest	[50]
25	2016–2020	3.643	in the middle	Weiramba forest	Dry Afromontane forest	[51]
26	2016–2020	lower	the lowest	Tore forest	Plantation forest	[52]
27	2021–2023	18.46	top five	Tulu Korma forest	Dry Afromontane forest	[53]
28	2021–2023	15.53	top ten	Harego forest	Dry Afromontane forest	[54]
29	2021–2023	154.9	1st	Hurubu forest	Dry Afromontane forest	[55]
30	2021–2023	148.5	1st	Gennemar forest	Dry Afromontane forest	[56]
31	2021–2023	(upper altitude) 43.06	1st	Werganbula forest	Dry Afromontane forest	[57]
32	2021–2023	(Edge) 32.49	2nd	Bale Mountains National Park forest	Moist evergreen montane forest	[13]
33	2021–2023	(Interior) 40.61	2nd	Bale Mountains National Park forest	Moist evergreen montane forest	[13]
34	2021–2023	6.72	in the middle	Gosh-Beret forest	Dry Afromontane forest	[58]
35	2021–2023	12.76	in the middle	Shoti forest	—	[59]
36	2021–2023	15.94	3	Menfeskidus Monastery forest	Dry Afromontane forest	[60]
37	2021–2023	41.7	2nd	Dindin forest	Dry Afromontane forest	[61]
38	2021–2023	149.5	1st	Less disturbed forest of Beyeda district	Dry Afromontane forest	[62]
39	2021–2023	136.8	1st	Moderately disturbed forest of Beyeda district	Dry Afromontane forest	[62]
40	2021–2023	149.2	1st	Highly disturbed forest of Beyeda district	Dry Afromontane forest	[62]

Table 1.
IVI status data of Juniperus procera *species.*

increasing altitude from 1500 to 1900 m.a.s.l and then decreased with the absence of mature trees at 2100 m in the Harenna forest, southeastern Ethiopia [72].

3.3 Status of conifer plant species in Ethiopia

3.3.1 Regeneration status of J. Procera *and* P. falcatus species

The regeneration status and IVI score of the species are an indicator of the species' health and sustainability, and hence of the forest ecosystem. The analysis indicated that *J. procera* had a good and fair regeneration status in equal percent in the time series of 1996–2000. However, no data was found during 2001–2005. Fair, poor, and not regenerating statuses were recorded in equal proportion in the 2006–2010 time series. Good (14.28%), fair (57.14%), and poor (28.57%) regeneration status were documented in the time series of 2011–2015. Good, poor, and not regenerating status

No	Time series	IVI score	Status	Forest name	Vegetation type	Sources
1	2006–2010	9.35	top ten	Hugumbirda-Gratkhassu National forest priority area	—	[30]
2	2011–2015	5.6	in the middle	Gendo forest	Moist evergreen montane forest	[35]
3	2011–2015	32.6	top five	Menagesha Amba Mariam forest	Dry Afromontane forest	[31]
4	2011–2015	19.62	top five	Gedo forest	Dry Afromontane forest	[32]
5	2011–2015	52.47	top three	Kimphe Lafa natural forest	Dry Afromontane forest	[63]
6	2011–2015	lower	the least	Boda forest	Dry Afromontane forest	[34]
7	2016–2020	18.21	3rd	Berbere forest	Moist evergreen montane forest	[64]
8	2016–2020	11.786	in the middle	Yegof forest	Dry Afromontane forest	[41]
9	2016–2020	24.8	3rd	Wabero forest	Moist evergreen montane forest	[65]
10	2016–2020	74.5	1st	Ades forest (West Hararghe Zone)	Dry Afromontane forest	[47]
11	2016–2020	74.15	top ten	Kumuli forest	Dry Afromontane forest	[37]
12	2016–2020	13.77	3rd	Chilimo forest	Dry Afromontane forest	[38]
13	2016–2020	49.06	1st	Ades forest (Southeastern Ethiopia)	Dry Afromontane forest	[40]
14	2016–2020	11.79	in the middle	Yegof forest	Dry Afromontane forest	[41]
15	2016–2020	42.87	2nd	Chilimo Gaji forest	Dry Afromontane forest	[42]
16	2016–2020	3.43	in the middle	Hugumburda forest	Dry Afromontane forest	[45]
17	2016–2020	1.7	the least	Coffee-based Zegie Peninsula forest	Dry Afromontane forest	[66]
18	2016–2020	0.49	the lowest	Non-coffee Zegie Peninsula forest	Dry Afromontane forest	[66]
19	2016–2020	70.29	1st	Munessa forest	Dry Afromontane forest	[67]
20	2016–2020	lower	the lowest	Tore forest	Plantation forest	[52]
21	2016–2020	50.35	1st	Asabot forest	Dry Afromontane forest	[68]
22	2016–2020	11.5	top ten	Gatira George's forest	Dry Afromontane forest	[49]
23	2016–2020	13.413	top ten	Gemechis forest	Dry Afromontane forest	[50]
24	2021–2023	17.14	top ten	Shoti forest	—	[59]
25	2021–2023	32.99	1st	Kenech forest	Moist evergreen montane forest	[69]
26	2021–2023	31.32	2nd	Tulu Korma forest	Dry Afromontane forest	[53]
27	2021–2023	48.9	top five	Hurubu forest	Dry Afromontane forest	[55]
28	2021–2023	91.5	2nd	Gennemar forest	Dry Afromontane forest	[56]
29	2021–2023	(upper altitude) 37.3	2nd	Werganbula forest	Dry Afromontane forest	[57]
30	2021–2023	(Edge) 13.44	top ten	Bale Mountains National Park forest	Moist evergreen montane forest	[13]
31	2021–2023	(Interior) 29.49	top five	Bale Mountains National Park forest	Moist evergreen montane forest	[13]

No	Time series	IVI score	Status	Forest name	Vegetation type	Sources
32	2021–2023	lower	the lowest	Tulu Lafto forest	—	[70]
33	2021–2023	lower	the lowest	Menfeskidus Monastery forest	Dry Afromontane forest	[60]
34	2021–2023	49.9	1st	Dindin forest	Dry Afromontane forest	[61]

Table 2.
IVI status data of P. falcatus *species.*

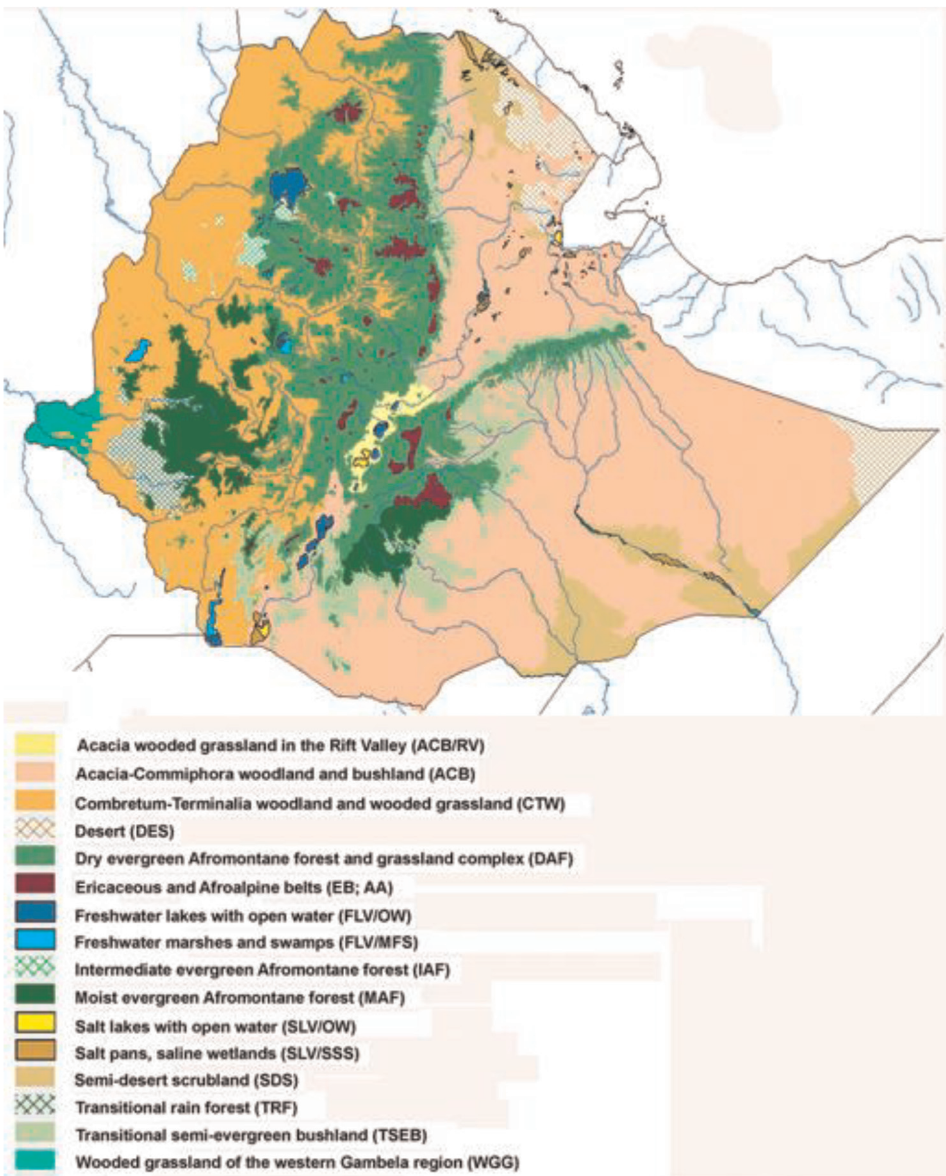

Figure 3.
Map of Ethiopian vegetation types. Source: [71].

were found in the same proportion each (20%) while, fair regeneration (40%) was found to have the highest percentage in the time of 2016–2020. *J. procera* had a good (12.5%) and fair (87.5%) regeneration status in the 2021–2023 time series (**Figure 4**). Overall, *J. procera* had the highest percentage of fair regeneration status than the other regeneration statuses from 2011 to 2015 to 2021–2023 time series.

The *J. procera* species is among the first highest density of naturally regenerated woody species with 369 individuals/ha in the case of Entoto Mountain and the surrounding area in Addis Ababa, Ethiopia, in recent times (2020) [79]. Similarly, [73] states that *J. procera* is one of the species with the highest seedling densities in Menagesha forest before 25 years. Contrary to this, [82] documented very few *J. procera* in the Wof-Washa natural forest before 28 years. Regarding soil seed bank distribution recent finding shows that *J. procera* was the third with the highest relative frequency in soil seed bank in the case of Buska Mountain in Ethiopia [83]. Recently, it has been noted that the effect of increased temperature due to climate change on the regeneration of forest species is a common problem at the global level as in the case of central Spain [84]. Nevertheless, the documented "good regeneration status" of the *J. procera* species is not satisfactory to ensure the species' healthiness and sustainability as the highest percentage is fair regeneration from 2011 to 2015 to 2023 time series. In the long run, if the regeneration status goes with a similar trend the species would be at risk.

The regeneration status analysis was also done for *P. falcatus* species. Hundred (100) percent of poor, fair, and good regeneration status were documented in the time series of 1996–2000, 2001–2005, and 2006–2010, respectively. Not regenerated (14.28%), poor (14.28%), fair (42.85%), and good (28.57%) regeneration status were documented in the time series of 2011–2015. The highest percentage in good regeneration status (77.78%) of *P. falcatus* species was observed than poor (11. 11) and fair (11. 11) in the time series of 2016–2020. Regeneration status that was not regenerated (16.67%), poor (16.67%), fair (33.33%), and good (33.33%) regeneration status were documented in the time series of 2021–2023 (**Figure 5**). Generally, *P. falcatus* species had an alternate regeneration status between fair and good from 2001 to 2005 to 2020–2023.

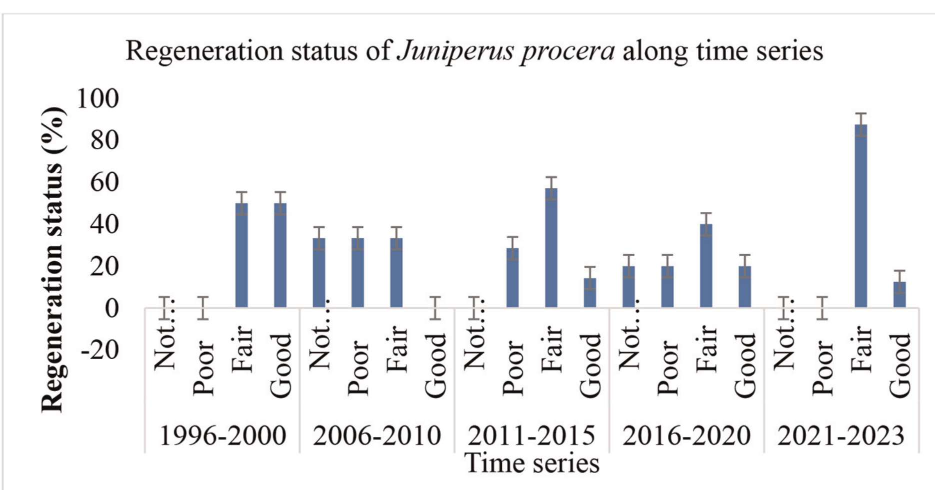

Figure 4.
Regeneration status of J. procera *along time series. Source: (see* ***Table 3****).*

***J. procera* species**				
No	**Time series**	**Regeneration status**	**Forest name**	**Source**
1	1996–2000	Good	Menagesha forest	[73]
2	1996–2000	Fair	Gara Ades forest	[73]
3	2006–2010	Fair	Boditi forest	[29]
4	2006–2010	Not regenerating	Denkoro forest	[74]
5	2006–2010	Poor	Adelle forest	[29]
6	2011–2015	Poor	Gedo forest	[32]
7	2011–2015	Fair	Menagesha Amba Mariam forest	[31]
8	2011–2015	Fair	Chilimo forest	[75]
9	2011–2015	Fair	Borana forests	[76]
10	2011–2015	Poor	Debirelibanos Monastery forest	[77]
11	2011–2015	Good	Yegof mountain forest	[78]
12	2011–2015	Fair	Gendo moist montane forest	[35]
13	2016–2020	Good	Entoto mountain and the surrounding area forest	[79]
14	2016–2020	Not regenerating	Gedo forest	[80]
15	2016–2020	Fair	Yerer mountain forest	[36]
16	2016–2020	Fair	Kumuli forest	[37]
17	2016–2020	Fair	Chilimo forest	[38]
18	2016–2020	Poor	Arero forest	[39]
19	2016–2020	Not regenerating	Dry Afromontane forests of Awi Zone	[44]
20	2016–2020	Poor	Tore forest	[52]
21	2016–2020	Fair	Asabot forest	[68]
22	2016–2020	Good	Ades forest	[47]
23	2021–2023	Fair	Tulu Korma forest	[53]
24	2021–2023	Fair	Hurubu natural forest	[55]
25	2021–2023	Good	Werganbula forest	[57]
26	2021–2023	Fair	Dindin natural forest	[61]
27	2021–2023	Fair	Harego forest	[54]
28	2021–2023	Fair	Gosh-Beret forest	[58]
29	2021–2023	Fair	Menfeskidus Monastery forest	[60]
30	2021–2023	Fair	Gamataja Community forest	[81]

Table 3.
Regeneration status data of Juniperus procera *species.*

The *P. falcatus* species is among the top ten species with the highest seedling densities in Gara Ades and Menagesha forest before 25 years [73]. Infection of *P. falcatus* by *C. uberata* in leaves, young stems, and fruit is documented in southeastern Ethiopia and central Ethiopia that could be a threat to the regeneration of

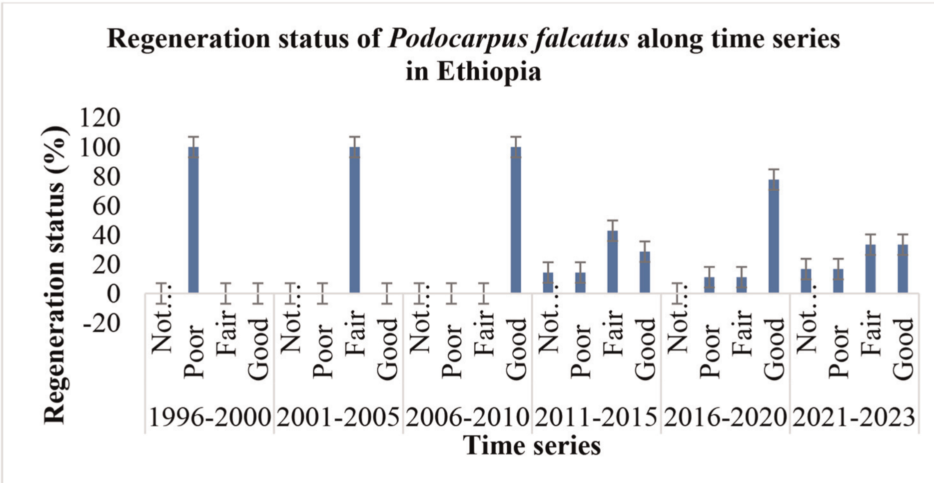

Figure 5.
Regeneration status of P. falcatus *along time series. Source: (see* ***Table 4****).*

***P. falcatus* species**				
No	**Time series**	**Regeneration status**	**Forest name**	**Source**
1	1996–2000	Poor	Gara Ades forest	[73]
2	1996–2000	Poor	Menagesha forest	[73]
3	2001–2005	Fair	Harena forest	[20]
4	2006–2010	Good	Munessa-Shashemene natural forest	[85]
5	2011–2015	Poor	Gedo forest	[32]
6	2011–2015	Fair	Menagesha Amba Mariam forest	[31]
7	2011–2015	Good	Debirelibanos Monastery forest	[77]
8	2011–2015	Good	Chilimo forest	[75]
9	2011–2015	Fair	Borana forests	[76]
10	2011–2015	Not regenerating	Yegof forest	[78]
11	2011–2015	Fair	Gendo moist Montane forest	[35]
12	2016–2020	Good	Kumuli forest	[37]
13	2016–2020	good	Chilimo forest	[38]
14	2016–2020	Good	Chilimo Gaji forest	[42]
15	2016–2020	Poor	Asabot forest	[68]
16	2016–2020	Fair	Munessa forest	[67]
17	2016–2020	Good	Gedo forest	[80]
18	2016–2020	Good	Berbere Afromontane moist forest	[64]
19	2016–2020	Good	Ades forest	[47]
20	2016–2020	Good	Dodola forest	[86]
21	2021–2023	Fair	Tulu Korma forest	[53]

P. falcatus species				
No	**Time series**	**Regeneration status**	**Forest name**	**Source**
22	2021–2023	Fair	Hurubu forest	[55]
23	2021–2023	Good	Werganbula forest	[57]
24	2021–2023	Good	Dindin forest	[61]
25	2021–2023	Not regenerating	Kenech forest	[69]
26	2021–2023	Poor	Gamataja community forest	[81]

Table 4.
Regeneration status data of P. falcatus *species.*

P. falcatus regeneration [87]. Furthermore, infected fruit ultimately led to the rotting of fruit and seed, which limited the seed source for *P. falcatus* regeneration of *P. falcatus* [87]. Even though the documented percent of "good regeneration status" of the *P. falcatus* species is decreasing from time to time, the documented good regeneration status does not indicate satisfactory to ensure the species' healthiness and sustainability. This is because in the time series of 2021–2023, the sum of the percentage of not regenerating and poor regeneration status is equal to good and fair regeneration status.

3.3.2 The dominance (IVI) status of the J. Procera *and* P. falcatus *species*

IVI score analysis shows that the *J. procera* scored top three, the lowest, top three, and top three classes in the time series of 2006–2010, 2011–2015, 2016–2020, and 2021–2023, respectively (**Figure 6**). This might indicate that *J. procera* tree is well adapted to the complex pressure of environmental and disturbance factors that regulate the distribution, abundance, and productivity of the species from previous to current conditions. Since [88] indicates the significant impact of altitude, aspect, slope, grazing, and human interference on species distribution and the formation of plant communities in dry Afromontane forest patches of northwestern Ethiopia. Even if *J. procera* is the dominant tree in the dry Afromontane forest of Ethiopia, it is one of the species that was observed with some stumps, few logs, and dead but standing individuals in the Denkoro forest [74].

The IVI score of *P. falcatus* was the top ten, top five, top three, and top three classes across the time series of 2006–2010, 2011–2015, 2016–2020, and 2021–2023, respectively (**Figure 7**). This indicated the increasing dominance trend of *P. falcatus* species along time series. This might be because *P. falcatus* will regenerate in matured forest and the matured forest could gradually dominated by *P. falcatus* species [25].

3.4 Effect of climate change on sustainability of conifer plant species in Ethiopia

Climate change is affecting living organism distribution in general and the effect will continue to influence the future distribution of living organisms. For example, ref. [89] indicated that all vegetation types are affected by climate changes and forests are affected by altering forest regeneration patterns, a decrease in dominance of conifer species, compositional and structural changes in forests, and upward migration of

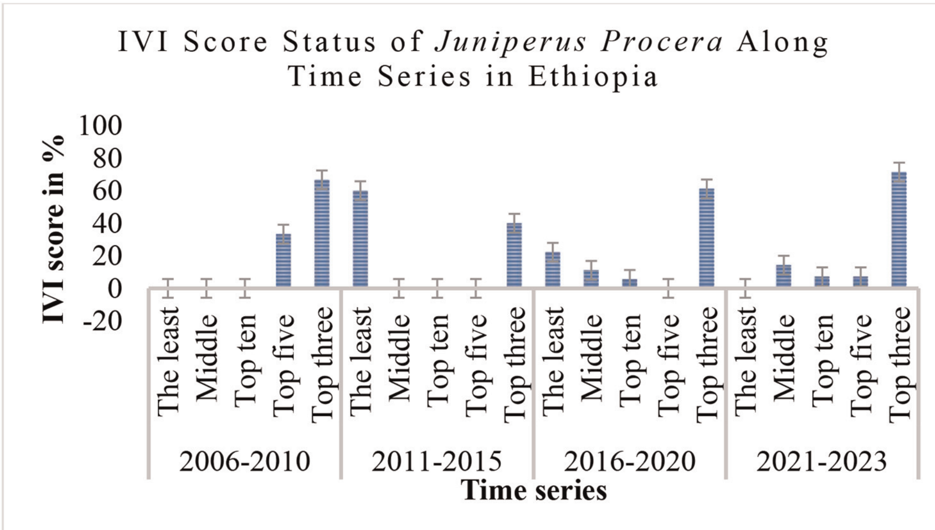

Figure 6.
IVI score status of J. procera *along time series. Source: (see* ***Table 1****).*

species in the mountains. For instance, ref. [90] states that endemic *Juniperus* species of China predicted to lose an entire of their suitable habitats due to change in temperature annual range and isothermality under full dispersal and RCP4.5 scenarios. Similar to this, suitable habitats of *J. procera* in Ethiopia will be decreased by 79.84, 91.17, 75.31, and 96.25% in Mid-century RCP2.6, Mid-century RCP8.5, End-century RCP2.6, and End-century RCP8.5 when compared with current distributions, respectively [91]. Furthermore, indicated that the annual growth of *J. procera* in Ethiopia is mainly controlled

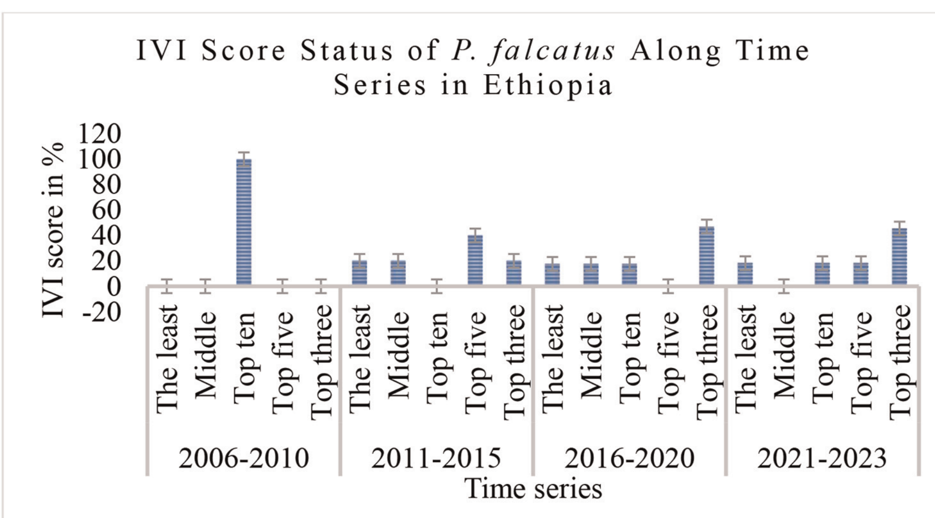

Figure 7.
Status of the IVI score of P. falcatus *along time series. Source: (see* ***Table 2****).*

by precipitation [92]. Similarly, [93] found that reduced rainfall will lead to high-level dieback of the *J. procera* species as observed in east-facing slopes than in west-facing slopes as the west-facing slope shows greener vegetation due to the aspect receiving higher rainfall in the case of Alsouda highlands, Saudi Arabia. Ref. [94] shows the poor regeneration status of *J. procera* under protected conditions after 3 years of enclosure and under open management systems in a dry Afromontane forest in northern Ethiopia, indicating that protecting the forest from livestock and human disturbance only is unlikely to lead to regeneration of this species. This might be due to moisture limitation as [95] states that poor soil moisture and nutrient conditions in dry highlands in Ethiopia result in low rates of seedling field survival and growth of native trees. Ref. [96] also states that woody plant species' seedling survival depends on both abiotic and biotic factors in an African montane forest. For instance, drought stress and potential heat stress affect the viability, growth potential, and photochemical efficiency of young *J. seravschanica* trees in the field in the case of the mountains of Oman [97].

P. falcatus was predicted to expand to higher elevations under RCP 4.5 and RCP 8.5. in the future (2070) in the case of South Africa [98]. Even though there is an environmentally suitable extensive area (>48%) in the southeastern escarpment of the main Ethiopian Rift for the *P. falcatus* species, only a small portion open-land area is practically available for rehabilitation since the area has been intensively cultivated to support the densely inhabited population [99]. From a regeneration point of view, seed germination of the *P. falcatus* species naturally occurred under the shed. For example, ref. [72] pointed out that about 74% of the seedling population of *P. falcatus* species was found in the shed and 26% in the open with a soil moisture content of between 15.6 and 27.2%, especially from 21.5 to 23.2%. Similarly, [86] recorded higher proportions of seedlings (79.45%) and saplings (72.05%) under canopy shades than in open areas with seedlings (20.6%) and saplings (27.95%). Therefore, decreased rainfall amount combined with increased temperature might influence the natural regeneration of conifer species by causing the moisture stress to the forest soil. Ref. [100] indicates positive and significant correlations when the tree-ring chronologies were compared with annual rainfall and rainfall at the main growing season but not for temperature, pointing to rainfall as the major climatic driver of plant growth in the dry Afromontane forest fragments of northern Ethiopia. Similarly, [101] shows the impact of the duration and frequency of periods of water limitation on forest structure and growth of dry tropical montane forests.

4. Conclusions and recommendations

J. procera and *P. falcatus* tree species are the only conifer plants that are found dominantly in the dry Afromontane forests of Ethiopia. However, dry Afromontane forests are sensitive to climate change mainly to decreasing rainfall and increased temperature. *J. procera* species exhibited fair regeneration status while *P. falcatus* exhibited alternating regeneration status between fair and good even in the face of climate change. IVI score of the species indicated that *J. procera* and *P. falcatus* species are dominant yet in dry Afromontane forests in the era of climate change. Overall, this result is an indicator that *J. procera* and *P. falcatus* tree species could be at risk in the long run if they continue with this trend. Therefore, thoughtful adaptation strategies should be designed and applied to dry Afromontane forests of the country to safeguard these conifer species from climate change and further degradation causes.

Specifically to *P. falcatus*, illegal felling of the preferred size of *P. falcatus* trees should be reduced and/or stopped because the presence of these big trees provides seed source and shed for the seedlings. The predicted suitable area should be set aside for the conservation of coniferous species of Ethiopia and the land use plan should be governed by suitability analysis of the area to climate change.

Furthermore, the effect of climate change on the spatial distribution of *J. procera* and *P. falcatus* should be further investigated because there are limited studies. Moreover, the effect of climate change on the soil moisture condition of dry Afromontane forests should be evaluated since the moisture condition of the soil is the critical factor that can determine the occurrence and success of natural regeneration of these species even if there are sufficient seed sources.

Conflict of interest

The authors declare that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this chapter.

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