REPTILES									
	DD	LC	NT	VU	EN	CR	EW	EX	
DD	0	140	17	19	39	14	0	0	**229**
LC	20	0	41	18	10	2	0	0	**91**
NT	3	64	0	21	20	2	0	0	**110**
VU	12	36	22	0	50	23	1	2	**146**
EN	10	13	9	21	0	39	0	1	**93**
CR	6	1	2	4	21	0	0	1	**35**
EW	0	0	0	1	0	1	0	1	**3**
EX	0	0	0	0	0	3	1	0	**4**

Figure 11: Total count of transitions taking place between the conservation statuses

Such datasets were also available for the previous years starting from 2007 to present(2022). These datsets were then imported in an excel file,cleaned and sorted out taxonomy wise (that is, species of mammalia, reptilia,amphibians,birds and plantae taxons were grouped separately) for further analysis.
Further, a count of the transitions taking place between the conservation statuses was taken taxonomy wise, as explained below.
For instance, the number of transitions that took place from the conservation status DD to EN is 39 (simply put, it indicates the number of species ,which were in the previous year under consideration, DD and in the following year they changed their status to EN)

The last column indicates the total number of transitions that took place **given some initial** conservation status. The individual probabilities were thus obtained by taking the proportion, that is,by dividing individual row values by the total value.
Thus, in the given scenario, the data can be expressed as a Markov chain as:-

$\{X_n : n \geq 1\}$ is a Markov chain with state space S={DD,LC,NT,VU,EN,CR,EW, EX} and the random variable X_n can be described as :
X_n : conservation status of a particular species belonging to a particular taxonomy group

The one step transition probability matrix for taxon reptilia was thus obtained as:-

REPTILES								
	DD	LC	NT	VU	EN	CR	EW	EX
DD	0	0.61135	0.07424	0.08297	0.17031	0.06114	0	0
LC	0.21978	0	0.45055	0.1978	0.10989	0.02198	0	0
NT	0.02727	0.58182	0	0.19091	0.18182	0.01818	0	0
VU	0.08219	0.24658	0.15068	0	0.34247	0.15753	0.00685	0.0137
EN	0.10753	0.13978	0.09677	0.22581	0	0.41935	0	0.01075
CR	0.17143	0.02857	0.05714	0.11429	0.6	0	0	0.02857
EW	0	0	0	0.33333	0	0.33333	0	0.33333
EX	0	0	0	0	0	0.75	0.25	0

Figure 12: One step transition probability matrix for reptiles

Similarly, repeating the above procedure, the one step transition probability matrix for different taxonomies(mammals,birds,amphibians and plants) was obtained.

The further Markov chain analysis was performed on R-Software.(Refer Appendix for code)

```
MC1
 A  8 - dimensional discrete Markov Chain defined by the following states:
 DD, LC, NT, VU, EN, CR, EW, EX
 The transition matrix  (by rows)  is defined as follows:
           DD         LC         NT         VU         EN         CR          EW         EX
DD 0.00000000 0.61135371 0.07423581 0.08296943 0.1703057 0.06113537 0.000000000 0.00000000
LC 0.21978022 0.00000000 0.45054945 0.19780220 0.1098901 0.02197802 0.000000000 0.00000000
NT 0.02727273 0.58181818 0.00000000 0.19090909 0.1818182 0.01818182 0.000000000 0.00000000
VU 0.08219178 0.24657534 0.15068493 0.00000000 0.3424658 0.15753425 0.006849315 0.01369863
EN 0.10752688 0.13978495 0.09677419 0.22580645 0.0000000 0.41935484 0.000000000 0.01075269
CR 0.17142857 0.02857143 0.05714286 0.11428571 0.6000000 0.00000000 0.000000000 0.02857143
EW 0.00000000 0.00000000 0.00000000 0.33333333 0.0000000 0.33333333 0.000000000 0.33333333
EX 0.00000000 0.00000000 0.00000000 0.00000000 0.0000000 0.75000000 0.250000000 0.00000000
```

Figure 13: One step TPM in R

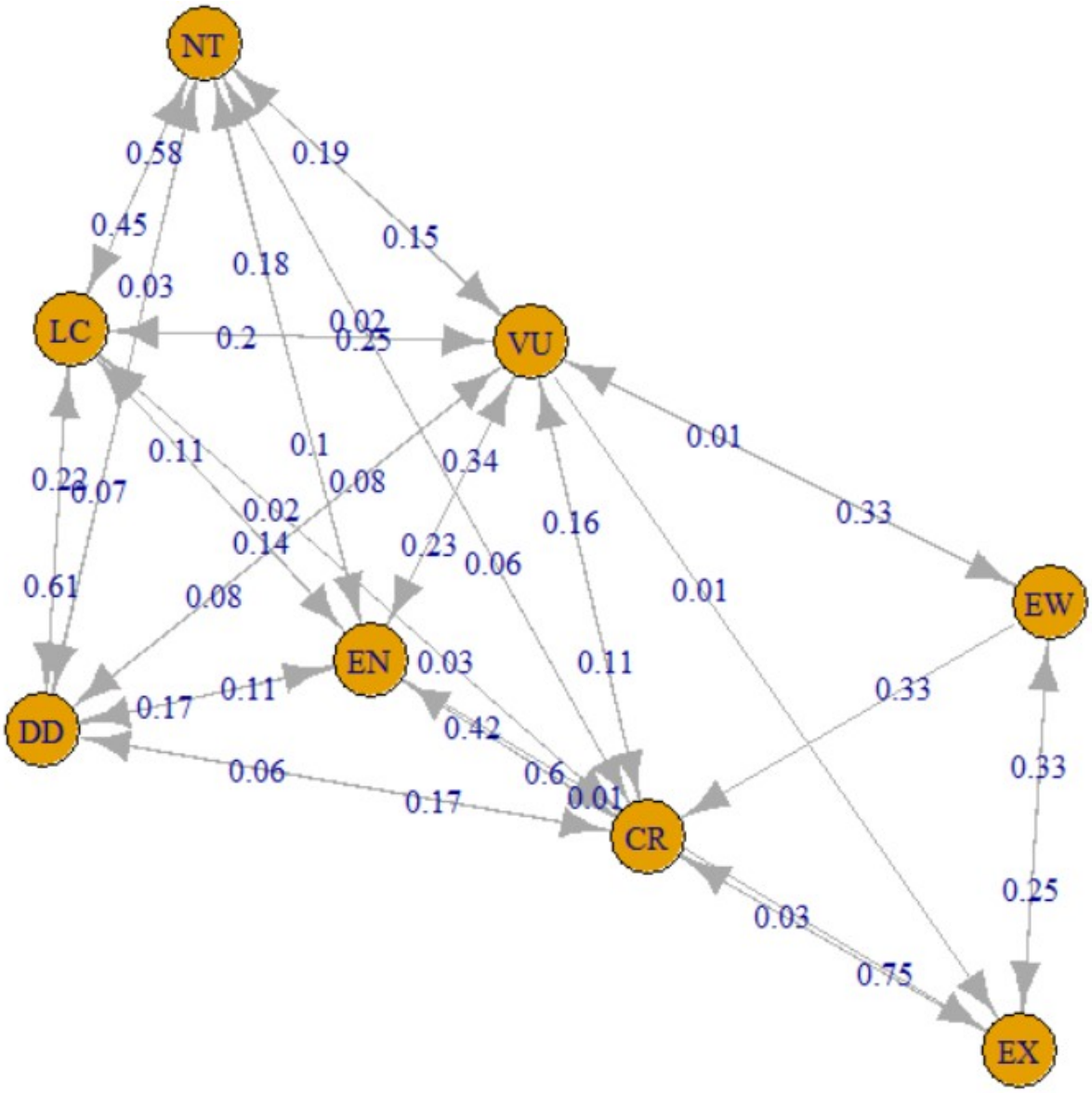

Figure 14: Sample Markov Chain plot

To begin with the analysis of the above Markov chain, it imperative to understand the nature of the individual states(that is, to check which states are persistent,transient,absorbing etc.) so as to get some initial insights.

Using the R code given in the appendix, it was inferred that all the states are **persistent**

```
> summary(ml_trans_r)
MCl  Markov chain that is composed by:
Closed classes:
DD LC NT VU EN CR EW EX
Recurrent classes:
{DD,LC,NT,VU,EN,CR,EW,EX}
Transient classes:
NONE
The Markov chain is irreducible
The absorbing states are: NONE
```

Figure 15: Corresponding output,summarising nature of all states

Interpretation:- It indicates that all states are persistent, that is regardless of the initial/current conservation status of a particular species, it has positive chances of re-entering other states; which means although any species's current conservation status may not indicate that it is threatened, in the near future, it is susceptible towards being threatened and facing increasing risks of extinction.

Thus based on the above interpretation, it can be said that, irrespective of whether a species is threatened or not, it cannot be directly inferred that a species classified as LC(Least Concern) or NT(Near Threatened) need not require any initial care and precautions for their conservation. Hence, when it comes to conservation of bio-diversity, neglecting the biological importance of species in the LC or NT categories is neither advisable nor correct.

After having understood the nature of the individual states, it is also important to comprehend what would possibly be the conservation status of a particular species after a certain number of years. As time increases (or as $t \to \infty$), however it is observed that the probabilities in the one step TPM converge to a particular value. This principle is called as steady states.

For demonstration, a plot was made by plotting the transition probabilities against the probabilities of TPM at the nth year (or nth step) with 'DD' as a conservation status being the initial one.(for simplicity and ease, graphs for transitions to states 'EW' and 'EX' have not been plotted)

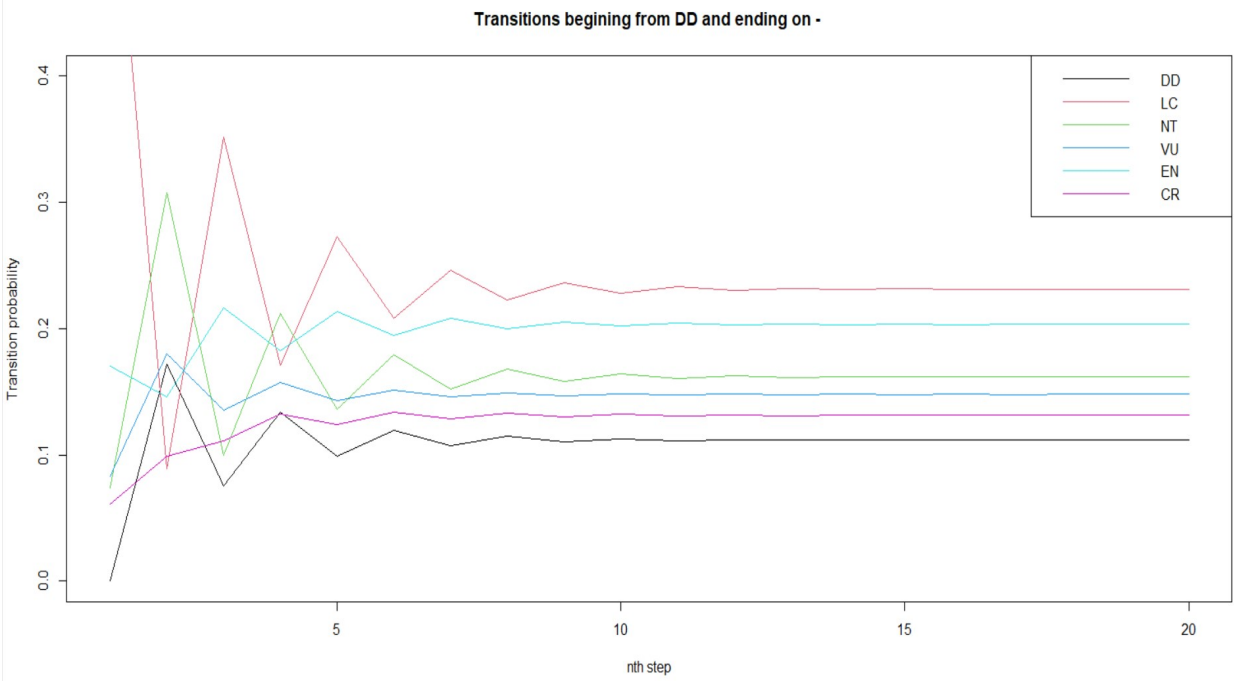

Figure 16: Plot demonstrating steady states

The steady states for the taxonomy of reptiles was thus obtained as:-

```
> ss=steadyStates(ml_trans_r);ss
           DD       LC        NT        VU        EN        CR          EW          EX
[1,] 0.1117838 0.231238 0.1619645 0.1479608 0.2033732 0.1313424 0.003278189 0.009059037
>
```

Figure 17: Steady state vector of animals belonging to taxonomy reptiles

For visualisation,the plot of the steady state is :-

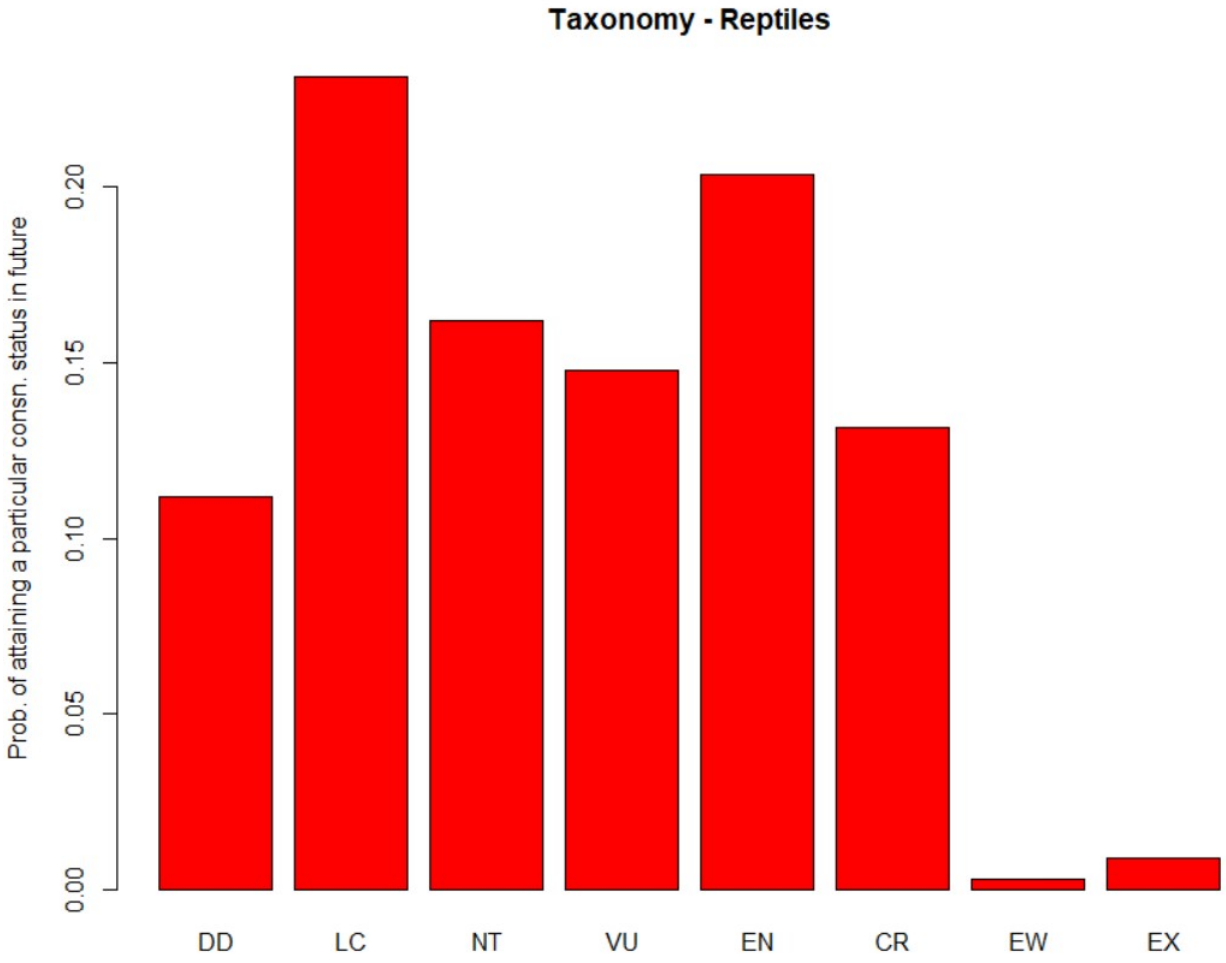

Figure 18: Bar plot of the steady states

Interpretation:- The above vector gives us the long term probabilities of attaining a given conservation status. For instance, we can infer that the probability of a particular species(from taxonomy reptilia) will become endangered is approximately 0.2033732.

Simulations using R

```
> sim_r1=rmarkovchain(n=20,ml_trans_r,t0='LC');sim_r1
 [1] "EN" "LC" "NT" "LC" "VU" "LC" "NT" "VU" "CR" "EN" "LC"
[12] "DD" "LC" "NT" "VU" "EN" "DD" "LC" "VU" "LC"
> sim_r1=rmarkovchain(n=20,ml_trans_r,t0='NT');sim_r1
 [1] "LC" "VU" "NT" "VU" "EN" "VU" "LC" "DD" "EN" "CR" "EN"
[12] "VU" "LC" "DD" "LC" "NT" "VU" "NT" "LC" "EN"
> sim_r1=rmarkovchain(n=20,ml_trans_r,t0='VU');sim_r1
 [1] "NT" "VU" "EN" "VU" "CR" "EN" "CR" "DD" "LC" "DD" "CR"
[12] "EN" "VU" "DD" "LC" "NT" "LC" "DD" "LC" "NT"
> sim_r1=rmarkovchain(n=20,ml_trans_r,t0='EN');sim_r1
 [1] "DD" "LC" "NT" "EN" "CR" "EN" "VU" "EN" "CR" "EX" "EW"
[12] "VU" "LC" "NT" "LC" "NT" "VU" "EN" "LC" "NT"
> sim_r1=rmarkovchain(n=20,ml_trans_r,t0='CR');sim_r1
 [1] "EN" "CR" "VU" "EN" "CR" "EN" "DD" "LC" "NT" "LC" "NT"
[12] "VU" "NT" "VU" "NT" "LC" "VU" "LC" "NT" "LC"
>
```

Figure 19: Simulation for different conservation status of taxon reptilia for a period of 20 years

In this very similar manner, the nature of the states and steady states for the other taxons were computed and their bar plots were plotted for better visualisation.

The nature of the states of the Markov chains of different taxons are:-

Taxon name	Recurrent states	Nature of Markov chain
Mammals	All	Irreducible
Birds	All	Irreducible
Amphibians	All	Irreducible
Plants	All	Irreducible

The steady states for the remaining taxons are:-

```
> ssm                    # Steady states for mammals taxon
            DD        LC        NT        VU        EN        CR         EX
[1,] 0.03393349 0.1472259 0.1655445 0.2576513 0.2612462 0.1235653 0.01083333
> ssb                    # Steady states for birds taxon
             DD        LC       NT        VU        EN        CR          EX
[1,] 0.004723902 0.2383209 0.281048 0.2318464 0.1654953 0.0708089 0.007756653
> ssa                    # Steady states for amphibians taxon
            DD        LC        NT        VU        EN        CR         EW          EX
[1,] 0.07251541 0.2333064 0.1411952 0.1997426 0.2029122 0.1179508 0.02537913 0.006998365
> ssp                    # Steady states for plants taxon
           DD        LC        NT        VU        EN        CR          EW          EX
[1,] 0.070683 0.2244427 0.1362042 0.2185463 0.2285773 0.1085713 0.008620126 0.004355124
>
```

Figure 20: Steady states of Mammals,Birds, Amphibians and Plants taxon respectively

The corresponding bar plots for the steady state of each taxon are:-

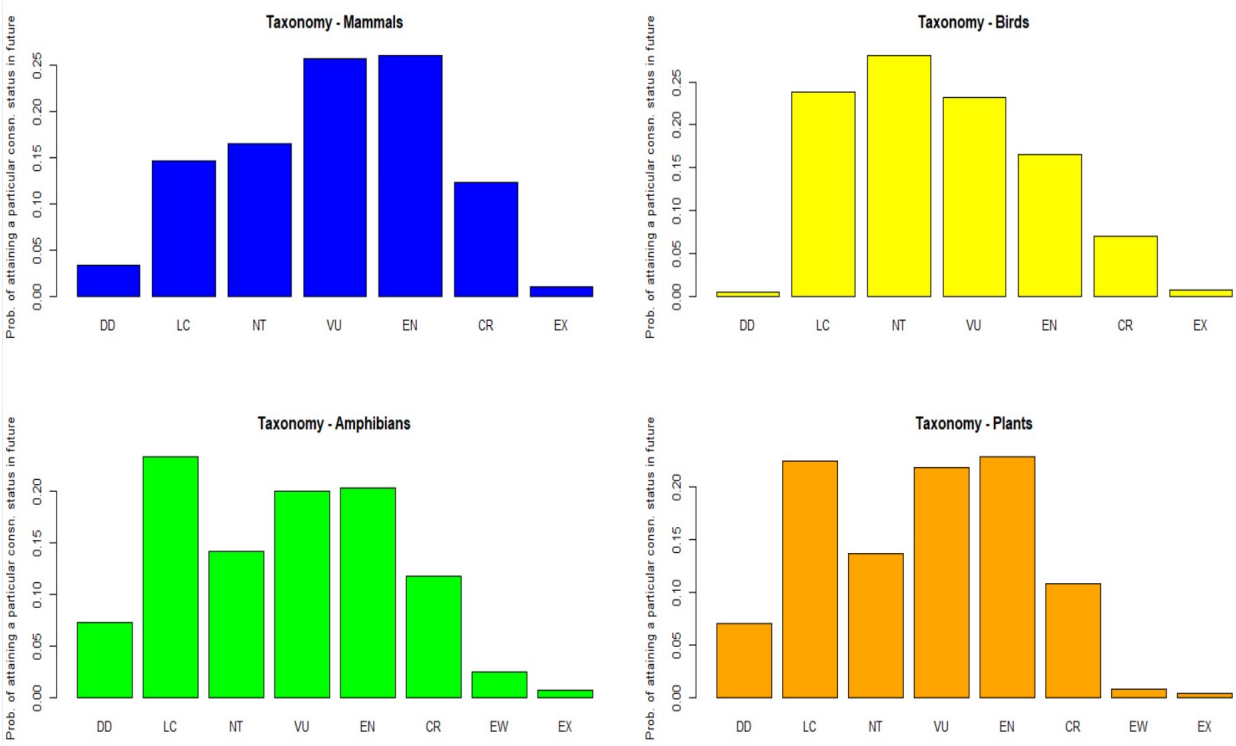

Figure 21: Visualisations of steady states