Supplementary Text 1

Damage and management costs

The cost model developed by Ahmed et. al. (2021) predicts the temporal cost dynamics in a scenario where management is introduced after the arrival and establishment of an invasive alien species. The model assumes that the potential damage cost D in the absence of management action follows a bell-shaped curve (logistic distribution), given as:

$$D(t) = \frac{r^2K^2e^{-rt}}{D_0\left(1+\left(\frac{rK}{D_0}-1\right)e^{-rt}\right)^2}, \quad D(0) = D_0, \quad D(\infty) = 0 \qquad \text{(S1)}$$

where D_0 is the estimated damage cost at the time of the first cost record (t = 0), r is the intrinsic cost growth rate and K is the cost carrying capacity (i.e., the accumulated damage cost in the long term). The maximum potential damage cost is $D_{max} = \frac{r^2K^2}{4(rK-D_0)}$ at time $t = \frac{1}{r}\ln\left(\frac{rK}{D_0} - 1\right)$.

Similarly, the management cost M is also modelled as a bell-shaped curve with introduction at τ years, given by:

$$M(t-\tau) = \frac{r_M^2K_M^2e^{-r_M(t-\tau)}}{2M_0\left(1+\left(\frac{r_MK_M}{2M_0}-1\right)e^{-r_M(t-\tau)}\right)^2} \cdot H(t-\tau), \quad M(0) = M_0, \quad M(\infty) = 0 \qquad \text{(S2)}$$

where $H(t-\tau)$ is a unit step function with value 0 if $t < \tau$, $\frac{1}{2}$ if $t = \tau$ and 1 if $t > \tau$ and M_0 is the estimated management cost at the time of introduction. The maximum management cost is $M_{max} = \frac{r_M^2K_M^2}{4(r_MK_M-2M_0)}$ and occurs at time $t = \frac{1}{r_M}\ln\left(\frac{r_MK_M}{2M_0} - 1\right) + \tau$.

Management efficiency

Management efficiency E is modelled as a function of time:

$$E(t-\tau) = 1 + \frac{(E_0-1)(E_1-1)}{(E_0-1)+(E_1-E_0)e^{-\alpha(t-\tau)}}, \quad 0 < E_0 < E_1 \tag{S3}$$

where E_0 is the initial efficiency value when management is introduced at time $t = \tau$, α is the efficiency growth rate, and E_1 serves as a maximum efficiency value in the case $\alpha > 0$, or otherwise regulates the shape of the efficiency curve. The efficiency function E quantifies the amount of reduction in the damage cost for every $1 spent on management over time. For more details on the behaviour of the management efficiency function E, see Ahmed et al. (2021).

Realised damage cost

Once management is introduced at $t = \tau$, it is assumed that the potential cost of damages D is reduced at an amount proportional to the time-dependent management efficiency E, referred to as the realised damage cost D^*, given by:

$$D^*(t,\tau) = D(t) - E(t-\tau) \cdot M(t-\tau) \tag{S4}$$

which is a positive quantity, or otherwise equal to zero.

Total cost

The total cost T is the sum of realised damage and management costs:

$$T(t,\tau) = D^*(t,\tau) + M(t-\tau). \tag{S5}$$

Management is deemed to be 'effective' only if the total cost T is less than the potential cost due to damages D, which occurs if damage costs decrease by an amount greater than $1 for every $1 spent on management and is otherwise considered ineffective.

Cost of inaction

The cost of inaction φ is the additional cost at time t incurred due to delayed management at time τ relative to a scenario where management is introduced at an earlier time τ^*, given as:

$$\varphi(t,\tau) = T(t,\tau) - T(t,\tau^*), \;\; \tau > \tau^* \tag{S6}$$

which is a positive quantity, or otherwise equal to zero. The cumulative cost of inaction Φ is then given by:

$$\Phi(t,\tau) = \int_0^t [T(t',\tau) - T(t',\tau^*)]\, dt' \tag{S7}$$

which is the total additional expenditure at time t due to management delay.

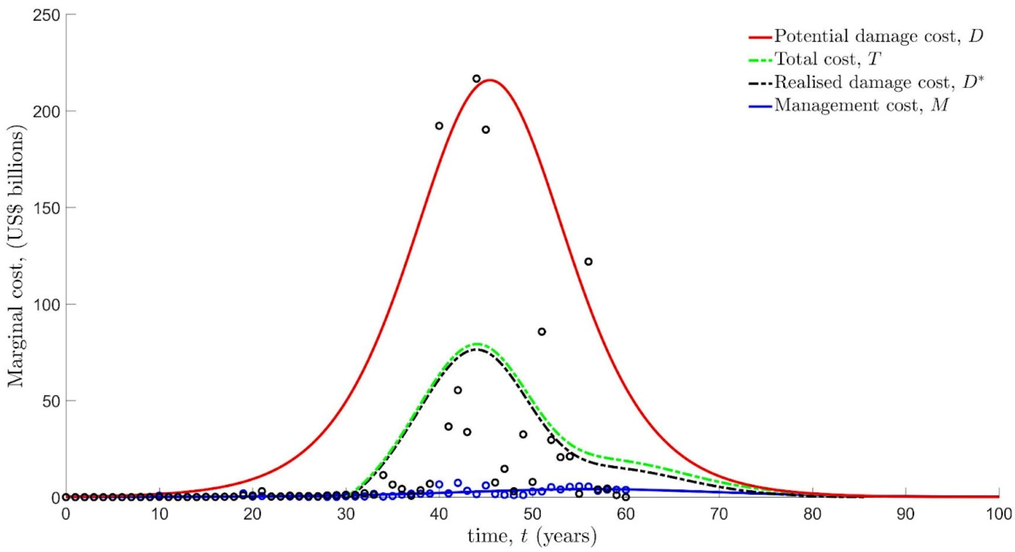

Figure S1. Cost curves for management M and the realised damage cost D^* given by Eqs. (S2) and (S4) fitted against the respective cost data. Management was introduced in the year 1960, at the same time as the first reported damage cost, thus corresponding to a delay time of $\tau^* = 0$. Estimated model parameters were obtained from the fitting and are given in Table S1. The strength of the model fitting was quantified by the coefficient of determination (R^2) and the root mean squared error ($RMSE$), with $R^2 = 0.61$, $RMSE$ = \$1.2 billion for management costs and $R^2 = 0.32$, $RMSE$ = \$37.9 billion for realised damage costs. The potential damage cost D (in the absence of management) and the total cost T were then determined from Eqs. (S1) and (S5).

Table S1. Estimated cost model parameters.

Management costs	**Parameters**	**Estimated values**
Intrinsic growth rate for management costs	r_M	0.1047 per year
Carrying capacity for management costs	K_M	157.96 US\$ billions
Management cost at the time of first cost detection	M_0	0.0231 US\$ billions
Damage costs		
Intrinsic growth rate for damage costs	r	0.1771 per year
Carrying capacity for damage costs	K	4873.02 US\$ billions
Damage cost at the time of first cost detection	D_0	0.2761 US\$ billions
Management efficiency		

Initial management efficiency	E_0	53.4925
Long term management efficiency	E_1	53.4928
Change in management efficiency	α	-0.2279 per year

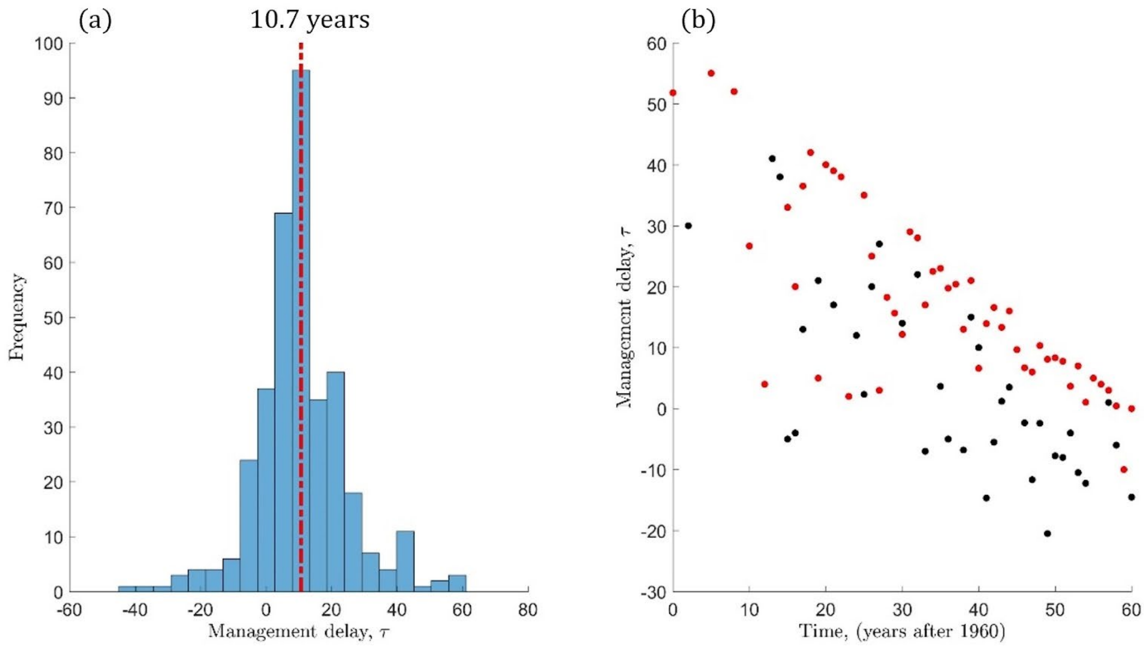

Figure S2. (a) Distribution of delay times for all 366 individual management scenarios across species and countries, with mean global delay of 10.7 years. (b) Average management delay per year from 1960 (t = 0) to 2020 (t = 60), indicating a decreasing trend in delay time whether plotted against the first year of reported damage costs (red dots) or the first year of management costs (black dots).

Table S2. Predicted costs of inaction for varying management delay times, computed from Eq. (S7).

Management delay time	Cost of inaction (US$ billions)	Management delay time	Cost of inaction (US$ billions)
0	0	31	2835.29
1	97.25	32	2876.7
2	203.14	33	2915.52
3	315.61	34	2951.91
4	432.8	35	2985.98
5	553.12	36	3017.86
6	675.21	37	3047.67
7	797.92	38	3075.53
8	920.32	39	3101.56
9	1041.64	40	3125.85
10	1161.25	41	3148.52
11	1278.65	42	3169.67
12	1393.46	43	3189.37
13	1505.16	44	3207.74
14	1612.85	45	3224.84
15	1716.4	46	3240.77

16	1815.76	47	3255.59
17	1910.89	48	3269.38
18	2001.82	49	3282.21
19	2088.57	50	3294.14
20	2171.18	51	3305.23
21	2249.72	52	3315.53
22	2324.29	53	3325.1
23	2394.97	54	3333.99
24	2461.88	55	3342.25
25	2525.14	56	3349.91
26	2584.87	57	3357.03
27	2641.2	58	3363.63
28	2694.27	59	3369.76
29	2744.22	60	3375.44
30	2791.18	...	…
		∞	3423.63

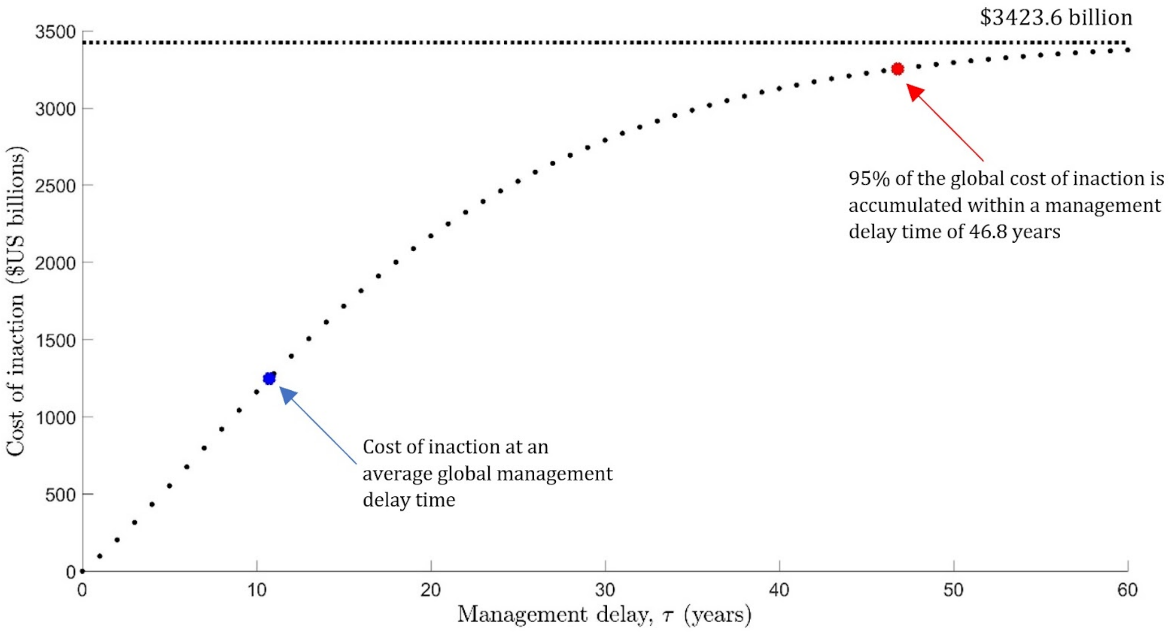

Figure S3. Global costs of inaction computed from Eq. (S7) using numerical integration (trapezoid rule). The cost is estimated in the long-term ($t \rightarrow \infty$) for different management delay times τ, relative to the scenario with immediate management action at $\tau^* = 0$. With an average global management delay time of 10.7 years, the cost of inaction is $1,247.2 billion (blue marker). The cost of inaction amounts to $3,423.6 billion in the long term, of which 95% is attained with a delay time of 46.8 years (red marker).

References

Ahmed, D.A., Hudgins, E.J., Cuthbert, R.N., Kourantidou, M., Diagne, C., et al. (2021) Managing biological invasions: the cost of inaction. ResearchSquare, pre-print. https://doi.org/10.21203/rs.3.rs-300416/v1