STUDY ON THE ABSORPTION OF PAHS BY *SUAEDA HETEROPTERA* UNDER HYDROPONIC CONDITIONS

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(Received 10th Dec 2023; accepted 13th Mar 2024)

Abstract. PAHs represent a prevalent form of environmental contamination. Efficiently managing PAH-induced pollution is a pivotal focus in contemporary environmental research and management. Globally distributed, *Suaeda heteroptera* exhibits robust bioaccumulation traits and also it can be grown sustainably, therefore, it is suggested to be used for its soil and water pollutant removal efficiency, particularly in the case of heavy metals. This study selected *phenanthrene* (PHE) and *benzo[a]pyrene* (BaP), as representative PAH mixtures with predefined concentrations. The research investigated *Suaeda heteroptera's* capability to mitigate PAHs under hydroponic conditions. Findings indicated concentration-dependent variations in *Suaeda heteroptera's* absorption capacity for PAHs. At a concentration of 100 μg/L, *Suaeda heteroptera* demonstrated the highest efficacy in reducing total PAHs, achieving a removal efficiency of 82.351 μg/kg/d. At concentrations of 10 μg/L, *Suaeda heteroptera* exhibited optimal reduction in PHE concentration, achieving a removal efficiency of 2.874 μg/kg/d. Regarding BaP, the most effective concentration reduction by *Suaeda heteroptera* occurred at a concentration of 100 μg/L, with a removal efficiency of 68.542 μg/kg/d. Over time, *Suaeda heteroptera* exhibited an increasingly significant removal effect on PAHs, notably at concentrations of 10 μg/L and 100 μg/L.
Keywords: *environmental pollutant, bioaccumulation ability, organic pollution removal, reduction capacity, concentration-dependent absorption*

Introduction

Since 1980, there has been a marked escalation in human developmental activities, notably seen in the significant upsurge in oil demand and extraction. This surge has led to a notable trend where wetlands are increasingly converted into oil facilities, causing substantial permeation of *polycyclic aromatic hydrocarbons* (PAHs) into the soil. The accumulation of these PAHs in the topsoil disrupts its structure (Lv and Cheng, 2001), exerting severe toxic effects on soil microorganisms and plants. This disruption hinders microbial growth and activity, upsetting the delicate balance of the soil ecosystem, and impeding plant growth and development. Consequently, this disruption contributes to a decline in vegetation, leading to soil degradation and potential groundwater contamination through soil pores, posing considerable risks to human health (Meng, 2015). The potential environmental impacts of oil exploration and development are substantial. Petroleum hydrocarbons significantly impact soil permeability, thereby affecting the growth of indigenous plant species (Li et al., 2001). Scholars conducted an investigation into landscape fragmentation in the intertidal zone of the Liaohe Estuary from 1985 to 2017 using remote sensing imagery. This study identified PAH pollution as a contributing factor to the increasing levels of fragmentation (Su et al., 2020).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_19591970

Polycyclic aromatic hydrocarbons (PAHs) represent persistent organic pollutants (POPs) soluble in organic solvents. Comprising multiple benzene rings arranged in clusters or linear structures (Shen, 2018), PAHs consist solely of carbon and hydrogen atoms (Tang, 2018). Capable of long-distance migration through the atmosphere, water bodies, and living organisms, PAHs accumulate in biota and are transferred along the food chain, posing threats to environmental sustainability and human health (Huang et al., 2012). Presently, over 100 PAH variants have been identified, categorized as gaseous PAHs (mostly low molecular weight, less toxic, and volatile, like PHE and anthracene) and particle-bound PAHs (mainly high molecular weight, less volatile, and more toxic post metabolic activation, such as BaP and pyrene) (Yao and Chen, 1987). In 1976, USEPA categorized 16 PAHs, including BaP, PHE, and anthracene, as priority-controlled pollutants (*Table 1*). By 2008, the list of priority-controlled pollutants had expanded to include 28 PAHs. With increasing awareness of the threat posed by PAHs to human and environmental health, most countries have incorporated PAHs into their environmental monitoring frameworks.

Table 1. *Physical and chemical properties of 16 PAHs provision by USEPA*

PAHs	**Abridge**	**Molecular formula**	**Molecular weight**	**Ring number**	**Logkow**	**Henry's Patm-m3/mol**
Naphthalene	NAP	C10H8	128.17	2	3.38	43.01
Acenaphthylene	Acy	C12H8	152.19	3	4.08	12.30
Acenaphthene	Ace	C12H10	154.21	3	3.92	14.97
Fluorene	Flu	C13H10	166.22	3	4.32	9.33
Phenanthrene	PHE	C14H10	178.23	3	4.48	4.47
Anthracene	Ant	C14H10	178.23	3	4.55	5.01
Fluoranthene	FLA	C16H10	202.25	4	5.16	1.45
Pyrene	Pyr	C16H10	202.25	4	4.79	1.32
Benzo[a]anthracene	Ba A	C18H12	228.29	4	5.78	0.0692
Chrysene	Chr	C18H12	228.29	4	5.32	0.45
Benzo[b]fluoranthene	BbF	C20H12	252.31	5	5.78	0.066
Benzo[k]fluoranthene	BkF	C20H12	252.31	5	6.16	0.059
Benzo[a]Pyrene	BaP	C20H12	252.31	5	6.27	1.112
Dibenzo[a,h]anthracene	DBA	C22H14	278.35	5	6.54	0.0076
Benzo[g,h,i]Pyrene	BPE	C22H14	276.33	6	6.9	0.034
Indeno[1,2,3-c,d]Pyrene	IPY	C22H12	276.33	6	6.7	0.035

Polycyclic aromatic hydrocarbons (PAHs) have a propensity for environmental accumulation, leading to cellular damage and disruption of normal biological growth upon organismal absorption. The swift expansion of coastal urbanization, industrial activities, and petroleum extraction has resulted in escalating PAH contamination within the coastal area. Recent years have witnessed ecological degradation in the Panjin Hong Beach ecosystem situated at the downstream estuary of the Liao River, attributed to aggravated environmental pollution. Owing to its distinctive geographical position, this region assumes a pivotal role in intercepting and purifying contaminants at the Liao River estuary while upholding environmental and ecological equilibrium in the Liaodong Bay and surrounding offshore zones. Investigations suggest a potential correlation between this phenomenon and the excessive accumulation of PAHs in the nearby water and soil.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_19591970

Consequently, there has been significant attention directed towards the development of efficient methods for PAH degradation and adsorption.

Suaeda heteroptera, a prevalent annual plant, thrives abundantly in the salt marshes of the Red Sea. Possessing tolerance to salt and alkali, it has the capacity to augment soil organic matter. This plant has demonstrated effective removal of heavy metals, including Cu, Zn, Pb, and Cd (Zhu et al., 2005; He et al., 2012). Because of its outstanding salt-alkali tolerance and capacity to reduce PAHs (*polycyclic aromatic hydrocarbons*) (Wang and Guo, 2021), this plant finds frequent application in the removal of pollutants like PAHs, PCBs (polychlorinated biphenyls), and OCPs (organochlorine pesticides) from highly saline-alkali soils. Furthermore, it is employed in wastewater treatment and the restoration of wetlands.

PAHs in plants primarily originate from two pathways: aboveground and belowground. PAH absorption by plants occurs through their leaves from the atmosphere, influenced by PAH morphology and concentration, alongside factors like leaf morphology, cuticle thickness, stomatal density, and trichome growth on the leaf surface. Additionally, plants uptake PAHs from soil and water via their root systems. Plants readily absorb low-molecular-weight PAHs with high water solubility, low lipid solubility, and low octanol-water partition coefficients through their root systems. Via water as a medium, absorbed PAHs are transported upwards to aboveground tissues through transpiration. On the contrary, PAHs of medium to high molecular weight, characterized by low water solubility, high lipid solubility, and high octanol-water partition coefficients, exhibit limited absorption through the root system. Consequently, they tend to adhere to plant roots, creating a hydrophobic layer that hinders nutrient uptake from the external environment, resulting in phenomena like decreased stomatal conductance in plants (Trapp and Mcfarlane, 1994). PAH uptake through the root system is further influenced by factors such as the inherent plant characteristics and the abundance of soil organic matter (SOM) in the surrounding environment. Various plants demonstrate distinct levels of PAH uptake, and disparities exist in the migration and transformation of PAHs among different tissues within the same plant. Coniferous plants exhibit a greater capacity for PAH uptake compared to broad-leaved plants, while the leaf surface demonstrates a higher capacity for PAH uptake than the root system (Luo et al., 2015). Researchers have identified a correlation between plant lipid content and the absorption of PAHs, suggesting that higher lipid content in plants increases their sensitivity to the absorption of PAHs (Cui et al., 2019). Scholars have found a direct correlation between the absorption rate of *polycyclic aromatic hydrocarbons* (PAHs) and the adaptability of plants (Ma and Zheng, 2016).

Currently, there have been numerous studies on the ability of *Suaeda heteroptera* to remove pollutants and the toxicity of PAHs to organisms. However, there is limited research on the reduction capacity of *Suaeda heteroptera* towards PAHs. Therefore, this study focuses on using *Suaeda heteroptera* as experimental material and sets up a hydroponic environment in the laboratory. Different concentrations of two types of PAHs with varying benzene ring numbers are employed to treat *Suaeda heteroptera*. The absorption of *Suaeda heteroptera* towards PAHs at different concentrations is observed and measured. This research aims to provide insights into the mechanisms underlying the removal of different PAHs by *Suaeda heteroptera*, and to contribute to the restoration efforts of coastal zones or red beaches.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Materials and methods

Experimental materials

The seeds of *Suaeda heteroptera* were purchased from Panjin City, Liaoning Province. The experimental soil used was potting soil. Based on the literature review, we selected different numbers of benzene rings, such as *naphthalene* and *benz[a]anthracene*, as representatives of the PAHs reagent mixture. The concentrations of PAHs mixture in this study were established. Both *naphthalene* and *benz[a]anthracene* were purchased from Shanghai Sangon Biotech Co., Ltd.

Instruments and reagents

The main instruments and reagents are listed below (*Tables 2, 3*):

Table 2. *Main instrument information table*

Number	Equipment/Reagent Name	Model/Type	Brand/Manufacturer
1	Electronic Balance	PB 602-N, Sensitivity 0.01g	Mettler Toledo, Switzerland
2	Micropipette	Eppendorf Research ®plus	Eppendorf, Germany
3	Intelligent Light Incubator	GXZ	Ningbo Dongbang Instrument Co., Ltd.

Table 3. *Main reagent information table*

Number	Reagent Name	Brand/Manufacturer
1	Acetone (1‰)	Chengdu Kelong Chemical Reagent Factory
2	Calcium Nitrate Tetrahydrate	Nanjing Reagent Co., Ltd.
3	Potassium Nitrate	Shanghai Yixin Chemical Co., Ltd.
4	Ammonium Nitrate	Shanghai Yixin Chemical Co., Ltd.
5	Magnesium Sulfate	Shanghai Yixin Chemical Co., Ltd.
6	Iron(II) Sulfate Heptahydrate	Jinan Xinwang Chemical Co., Ltd.
7	EDTA Disodium Salt	Jinan Xinwang Chemical Co., Ltd.

Experimental methods

Plant culture

One kilogram of soil was placed in plastic pots (outer diameter 13.5 cm, height 12 cm), with each pot seeded with 1.0 g (approximately 200 seeds) of *Suaeda heteroptera*. The pots were placed outdoors in a well-lit and ventilated area and watered daily with tap water to ensure soil moisture. After approximately 30 days, seedlings with a height of approximately 11 cm were selected for measurement.

PAHs mixture configuration

Using an electronic balance, accurately weigh 0.5 g of PHE and BaP (both PAHs purchased from Shanghai Shenggong Biotechnology Co., Ltd.). Acetone was added to a final volume of 1 L, and the prepared mixture of polycyclic aromatic hydrocarbons (PAHs)

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 22(3):1959-1970.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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was transferred into a 1 L amber reagent bottle. The bottle was sealed and stored at 4°C in a refrigerator for future use. When needed, the PAHs mixture could be diluted to different concentrations using Hogland nutrient solution. Due to the poor water solubility of the compounds under test, acetone was chosen as a co-solvent to facilitate dissolution. Therefore, the concentration gradient of the PAHs mixture ranged from 0 (acetone only), 1 μg/L, 10 μg/L, to 100 μg/L.

Hydroponic methods

Using deionized water, *Suaeda heteroptera* plants with uniform growth time and consistent growth conditions (approximately 11 cm in height) were thoroughly washed and transferred to Hoagland nutrient solution. They were then stabilized in a growth chamber under illumination for 2 days. On the 3rd day, different concentrations (0 μg/L, 1 μg/L, 10 μg/L, 100 μg/L) of PHE and BaP mixed solution were applied to *Suaeda heteroptera*. Each concentration was applied to approximately 25 *Suaeda heteroptera* plants, with two parallel groups maintained. Samples were collected every 3 days by washing and drying the *Suaeda heteroptera* seedlings, sealing them in bags, and sending them to the National Marine Environmental Monitoring Center for PAHs analysis. Nutrient solution was replaced while maintaining constant PAHs concentrations throughout the experimental period, which lasted for 9 days. The experiment was repeated three times.

Measurement methods

After careful consideration of various factors such as sampling frequency, analytical costs, and complexity of procedures, this study selected the ultrasonic extraction method to determine the content of 16 priority polycyclic aromatic hydrocarbons (PAHs) in *Suaeda heteroptera* plants (Long, 2017). This method offers advantages including low detection limits, high accuracy, and good reproducibility, with recovery rates of over 80% achieved within 20 minutes of spiking.

Accurately weigh 2.00-5.00 g of sediment (biomass), 2 g of anhydrous sodium sulfate, mix thoroughly, and immerse a circular filter paper cylinder completely with chromatography-grade hexane. Then, place the accurately weighed sediment (biomass) and anhydrous sodium sulfate inside. Transfer this mixture into a 100 mL stoppered glass cylinder. Add 60 mL of dichloromethane, followed by 50 μL of PAHs surrogate standard solution. Let it soak for 12 hours, followed by ultrasonic extraction for 20 minutes and a 5-minute settling period. Transfer the extract to a rotary evaporator flask. Repeat ultrasonic extraction twice using 20 mL of dichloromethane each time. Combine the extracts in the rotary evaporator flask. Add 1 mL of iso-octane and evaporate to dryness. Concentrate to 1 mL, add 1 g of copper powder, and proceed with purification.

Add hexane to the glass chromatography column, then sequentially add silica gel, neutral alumina, and anhydrous sodium sulfate to the column. Wash the column with 40 mL of hexane at a flow rate of 2 mL/min for 20 minutes and discard the washings. Transfer all the sample extract onto the column, then elute the column with dichloromethane (80 mL) at a flow rate of 2 mL/min. Collect all the eluent using a rotary evaporator flask and concentrate it to approximately 2 mL. Add 5 mL of hexane and continue concentrating to 1.0 mL. Transfer the concentrated solution to a sample vial, add 50 μL of deuterated triphenylene internal standard solution, mix well, and it is ready for analysis.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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Data processing

The data analysis was conducted using Excel 2022. One-way analysis of variance (ANOVA) and Duncan's multiple comparison tests were performed using SPSS 25. Differences with $P > 0.05$ were considered not statistically significant. The calculation formula for the removal capacity of polycyclic aromatic hydrocarbons (PAHs) by *Suaeda heteroptera* is provided below.

$$R_e = C_{PAHs_t} - C_{PAHs_0} \quad \text{(Eq.1)}$$

$$R_c = \frac{R_e}{T} \quad \text{(Eq.2)}$$

In *Equation (1) and (2)*, Re represents the amount of PAHs removed in the experimental group; C_{PAHst} represents the PAHs content at the end of the experiment; C_{PAHs0} represents the initial PAHs content in the experiment; R_c represents the removal capacity; and T represents the number of experimental days.

Results and discussion

Abatement of PAHs by Suaeda heteroptera under hydroponic conditions

The variation in the total content of PAHs within *Suaeda heteroptera* is illustrated in *Figure 1*. Overall, the total PAHs content in all treatment groups at day 9 exceeded that at day 0, with the highest observed at 100 µg/L treatment group on day 9, reaching 1438.65 µg/kg, representing a 98% increase compared to the control group. Additionally, there was a significant difference in the total PAHs content between the 100 µg/L treatment group and other treatment groups ($P < 0.05$). Taking the 100 µg/L treatment group as an example, the total PAHs content within *Suaeda heteroptera* increased rapidly from 0 to 3 days, followed by a gradual increase from 3 to 9 days, eventually stabilizing. Furthermore, as the concentration of PAHs increased, the ability of *Suaeda heteroptera* to remove PAHs also gradually increased, with the removal capacity of the 100 µg/L treatment group being 76.539 µg/kg/d higher than that of the control group (*Table 4*).

Table 4. *Removal capacity of Suaeda heteroptera to total PAHs*

Processing time (d)	**0µg/L (µg/kg)**	**1µg/L (µg/kg)**	**10µg/L (µg/kg)**	**100µg/L (µg/kg)**
0	640.083	814.813	659.977	697.491
3	876.579	675.502	857.052	1304.109
6	795.768	493.288	695.785	1411.509
9	692.391	943.529	1081.012	1438.648
Removal amount of each group	52.309	128.716	421.035	741.157
Removal capacity	5.812	14.302	46.782	82.351

Note: Data are averaged for each treatment group

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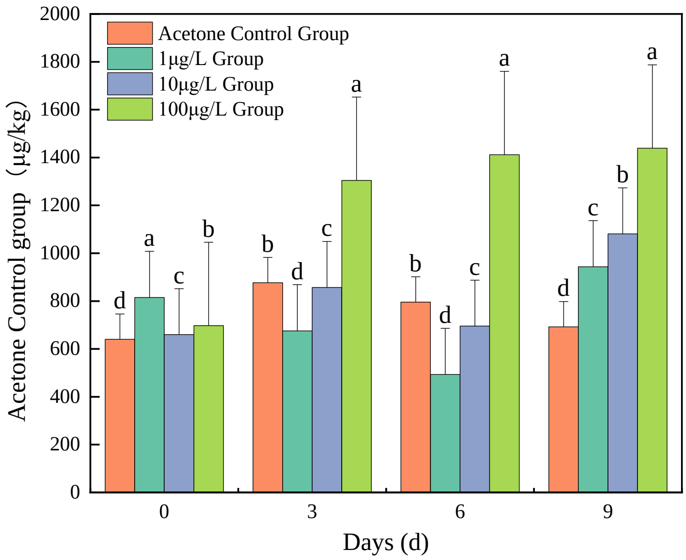

Figure 1. *Reduction of total PAHs by Suaeda Heteroptera under hydroponic conditions. Note: On the same day, significant differences are represented by different letters (P<0.05), while doubling indicates no significant differences (P>0.05), the same below. The error line in the figure is expressed by standard deviation, which is the mean of the distance of each data from the mean, the same below*

Ablation of Phenanthrene by Suaeda heteroptera under hydroponic conditions

From *Figure 2*, the fluctuation in PHE content within *Suaeda heteroptera* can be observed. Across all groups, the PHE content within *Suaeda heteroptera* in the 10 μg/L treatment group exhibited a trend of initially decreasing and then increasing from 0 to 9 days, reaching its peak on day 9 at 91.25 μg/kg. On the same day, the Phenanthrene content in other treatment groups was lower than that on day 0, and the difference in PHE content between this group and other treatment groups was significant ($P < 0.05$). On days 3 and 6, with the increase in PAHs concentration in the treatment groups, the PHE content showed a trend of initially decreasing and then increasing. However, on day 9, with the increase in PAHs concentration in the treatment groups, the PHE content exhibited a trend of initially increasing and then decreasing. As indicated in *Table 5*, with the increase in PAHs concentration, the removal capacity of PHE in each treatment group follows the order: control group < 1 μg/L < 100 μg/L < 10 μg/L.

Table 5. *PHE removal capacity of Suaeda Heteroptera*

Processing time(d)	**0μg/L (μg/kg)**	**1μg/L (μg/kg)**	**10μg/L (μg/kg)**	**100μg/L (μg/kg)**
0	77.163	82.450	65.386	63.531
3	57.047	44.231	56.512	85.093
6	67.482	44.847	47.646	54.295
9	36.970	55.517	91.250	56.602
Removal amount of each group	-40.1926	-26.9333	25.8636	-6.9291
Removal capacity	-4.446	-2.993	2.874	-0.770

Note: Data are averaged for each treatment group

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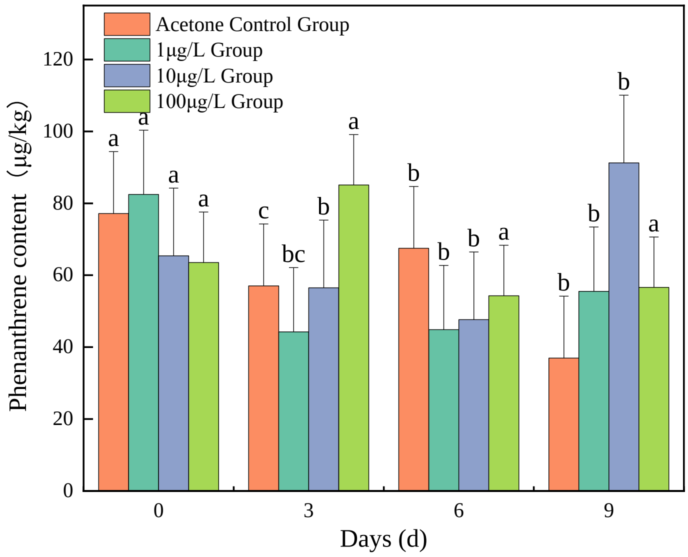

Figure 2. *Reduction of total PAHs by Suaeda Heteroptera under hydroponic conditions*

Ablation of Benzo[a]Pyrene by Suaeda Heteroptera under hydroponic conditions

From *Figure 3*, the variation in BaP content within *Suaeda heteroptera* under different PAHs concentrations is evident. Overall, there is an increasing trend in BaP content within *Suaeda heteroptera*. On day 6, at a concentration of 100 μg/L, BaP reached its maximum value, 773.98 μg/kg, while on the same day, the acetone control group exhibited the minimum value at 1.41 μg/kg. The BaP content within *Suaeda heteroptera* in the 100 μg/L treatment group significantly differed from that in other treatment groups ($P < 0.05$). Generally, except for day 0, at the same time point, BaP increased with the increase in PAHs concentration, with the most significant increase observed in the 10 and 100 μg/L treatment groups.

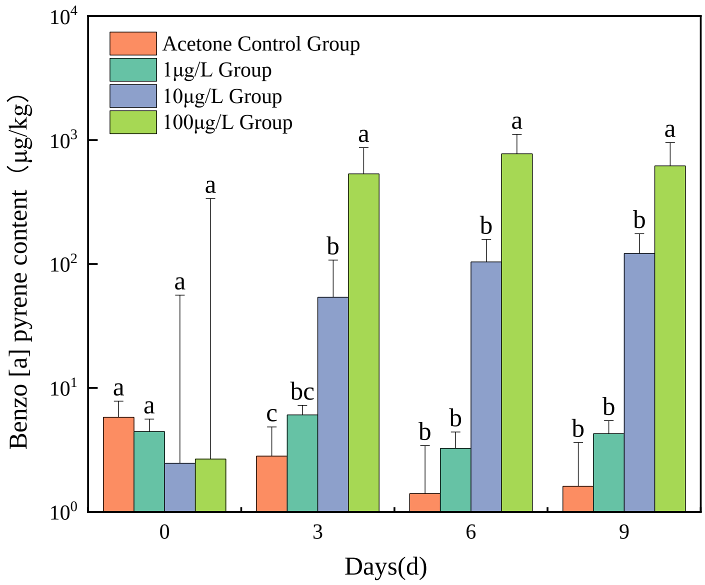

Figure 3. *Reduction of BaP by Suaeda Heteroptera under hydroponic conditions*

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DOI: http://dx.doi.org/10.15666/aeer/2203_19591970

As indicated in *Table 6*, the removal capacity of BaP by *Suaeda heteroptera* increases with the rise in PAHs concentration, with the 100 μg/L treatment group exhibiting the best removal effect, with a removal capacity of 68.542 μg/kg/d, approximately five times that of the 10 μg/L treatment group.

Table 6. *Removal rate of BaP by Suaeda Heteroptera*

Processing time(d)	0μg/L (μg/kg)	1μg/L (μg/kg)	10μg/L (μg/kg)	100μg/L (μg/kg)
0	5.798	4.446	2.466	2.671
3	2.812	6.072	53.878	533.715
6	1.407	3.253	103.931	773.977
9	1.610	4.278	121.667	619.545
Removal amount of each group	-4.1883	-0.1683	119.2008	616.8744
Removal capacity	-0.465	-0.019	13.245	68.542

Note: Data are averaged for each treatment group

After completion of all experiments, a single-factor analysis of variance was conducted on the removal capacities. The results, as shown in *Table 7*, yielded a significance value of 0.197. Comparing this value with the set significance level, it can be inferred that there is no significant difference in the dependent variable data between different levels.

Table 7. *One-Way Analysis of Variance (Removal Efficiency)*

ANOVA					
Removal capacity	**Square sum**	**Degrees of freedom**	**Mean square**	**F**	**Significance**
Intergroup	3001.51	2	1500.76	1.96	0.197
Within a group	6891.47	9	765.72		
Total	9892.98	11			

Discussion

Phytoremediation has long been renowned for its attributes of non-secondary pollution, low cost, and rapid efficacy. This experiment focuses on *Suaeda heteroptera* as the experimental subject, investigating its attenuation effects on PAHs, PHE, and BaP under hydroponic conditions at various PAHs concentrations. The absorption of PAHs by *Suaeda heteroptera* is influenced by the presence of organic matter in sediment, facilitating their enrichment within the plant. However, certain PAHs exhibit low mobility, hindering their absorption by plants (Gao et al., 2010). Previous studies have examined the absorption efficiency of *Suaeda heteroptera* for petroleum hydrocarbon pollutants using similar solution culture systems, observing an initial rapid increase in content followed by a decline, indicating the plant's capacity for pollutant absorption (Li, 2022), aligning with the findings of this study. Additionally, research suggests that *Suaeda heteroptera* achieves removal rates of over 90% for petroleum hydrocarbons at different growth stages, with better removal effects observed in the medium and high concentration treatment groups (Zhao, 2022). Notably, *Suaeda heteroptera* demonstrates superior removal capabilities during the seedling stage compared to the growth stage,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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indicating its ability to degrade polycyclic aromatic hydrocarbons in the environment, consistent with the objectives of this experimental study.

The results of this experiment indicate a cumulative trend in the total content of PAHs within *Suaeda heteroptera*. On the same day, the total PAHs content in other treatment groups is consistently higher than that in the control group. Significant differences are observed between the highest concentration treatment group and the control group regarding the total PAHs content within *Suaeda heteroptera*, demonstrating a notable increase in the reduction effect of total PAHs with increasing PAHs concentration, with the highest concentration treatment group exhibiting the most effective reduction. Furthermore, the content of PHE within *Suaeda heteroptera* shows a fluctuating trend, reaching its maximum on day 9, indicating the most effective reduction of PHE at this concentration. Taking day 9 as an example, with increasing concentration, the content of PHE within *Suaeda heteroptera* shows a trend of initial increase followed by decrease, and on the same day, the content of PHE within *Suaeda heteroptera* in all treatment groups (except the 10 μg/L treatment group) is lower than that on day 0, indicating that *Suaeda heteroptera* exhibits optimal removal capacity for PHE at a PAHs concentration of 10 μg/L. Moreover, the content of BaP within *Suaeda heteroptera* also varies, increasing with increasing PAHs concentration in all treatment groups (except day 0). The content of BaP within *Suaeda heteroptera* in the high concentration treatment group significantly differs from that in the control group ($P < 0.05$), with the reduction effect of BaP by *Suaeda heteroptera* increasing with higher PAHs concentration, and the high concentration treatment group demonstrating the best removal effect.

Conclusion

Through hydroponic experiments, the study investigated the attenuation effects of under different concentrations of PAHs. *Suaeda heteroptera* demonstrates an attenuation effect on PAHs. Under hydroponic conditions, *Suaeda heteroptera* absorbed a certain amount of PAHs in treatment groups with different concentrations, and the reduction effect of total PAHs by *Suaeda heteroptera* was most pronounced at a PAHs concentration of 100 μg/L, with a removal capacity of 82.351 μg/kg/d. When the PAHs concentration was 10 μg/L, *Suaeda heteroptera* exhibited the best reduction effect on PHE, with a removal capacity of 2.874 μg/kg/d. At a PAHs concentration of 100 μg/L, *Suaeda heteroptera* demonstrated optimal reduction effect on BaP, with a removal capacity of 68.542 μg/kg/d. The attenuation effect of *Suaeda heteroptera* on PAHs was more significant at concentrations of 10 and 100 μg/L.

This study solely investigated the attenuation effects of *Suaeda heteroptera* on PAHs under hydroponic conditions. *Suaeda heteroptera*, as a plant-based ecological restoration material, could further explore its combined application with other phytoremediation materials to enhance the remediation efficiency of PAHs and other organic pollutants. Additionally, the mechanisms and influencing factors of *Suaeda heteroptera*'s adsorption capacity for PAHs require further exploration. Unveiling the absorption mechanism of *Suaeda heteroptera* for PAHs would contribute to understanding the substance transfer and transformation laws during the biological adsorption process, thus improving the stability and reliability of its adsorption performance. Moreover, future research could focus on the migration and transformation of PAHs within *Suaeda heteroptera* and the kinetic study of PAHs enrichment by *Suaeda heteroptera*, conducting relevant experiments in pot or field plots.

Funding Projects. "Research and Application of Key Technologies for Green and Ecological Cultivation of Laminaria in Liaoning" (2020ZD23SN009), Major Science and Technology Project of Dalian City; Key Special Project on "Marine Environmental Security" of the National Key Research and Development Program (2019YFC1407700); Public Welfare Industry Research Project of the State Oceanic Administration (201305002); Local Service Project of the Liaoning Provincial Department of Education (DL201804); Open Fund of the Key Laboratory of Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration (201309, 201809).

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